The Impact of Water Conservation and Climate Change on Urban Water Demand

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ABSTRACT

The impacts of climate change on our lifestyle are not completely known. Climate change, population, and water are all important in determining water availability. Many studies have attempted to quantify climate change. Readily available temperature data can simply emulate climate change conditions in a comparison to water demand and serve as a proxy for climate change. In this study I characterize consumer water demand for Oakland, California over the last 35 years and examine its relationship with climate change via temperature. This study analyzes consumer demand based on EBMUD consumption and local temperature data and discovers the strength of trends via statistical analyses. My study questions the impact of temperature on urban water demand under the assumption that temperature is a valid indicator of climate and provides insight on how water demand might change due to climate change. My results show that consumers consume more water during non-drought conditions and summer seasons. Although my study shows a significant and relevant relationship between temperature and consumption, there are limitations of a small sample size, as well as indirectly considering price and policy. This study serves as a step towards understanding how to best manage water in a climate influenced future.

KEYWORDS

EBMUD, Oakland, temperature, consumption, demand

INTRODUCTION

Given the numerous uncertainties surrounding the topic of climate change, the impacts that the process could potentially have on our lifestyle are not completely known. (Reilly 2003). Long-term impacts of climate change will decrease water supply in California, and along with the increasing population, could lead to a water shortage (Standish-Lee & Lecina 2008). Climate change, which will prolong and intensify precipitation and drought conditions, will increase severity of future events in terms of water shortages (Gergis & Fowler 2009). Previous studies have investigated some of this uncertainty, but most have done so generally and have not examined how consumer demand for freshwater relates to climate change and water supply (Barnett et al. 2008).

Climate change, population, and water all play an important role that affects how much water supply is available. For example, California's population is steadily increasing and the amount of water demanded will also increase with this population growth (Harou et al. 2008). Generally, it is commonly accepted that the severity of drought events resulting from climate change will increase as time progresses (Gergis & Fowler 2009). Consequently, in terms of availability to consumers, is decreasing, while consumer accounts, or water connections, which represent demand, are steadily increasing as a result of population growth (Groves 2008). A sound understanding of the relationship between climate change and water demand is absolutely essential in order to maximize efficiency of water management and address a gap in knowledge (O'Hara and Georgakakos 2008). Until this relationship is completely understood, management of water supply in response to climate change will not be ideal and, because of uncertainties, we cannot adequately plan for the future (Xu et al. 2004). Site specific studies have been performed globally, but because of unique local environmental conditions, results are not necessarily generalizable to all systems (Ceballos-Barbancho et al. 2008) (Diaz et al. 2007) (Grafton & Kompas 2007).

A number of approaches have been proposed to quantify climate change, however readily available temperature data, an aspect of weather, can simply emulate climate change conditions in a comparison to water demand and serve as a proxy for climate change (Gergis & Fowler 2009). By using temperature, a measure of weather, we can visualize how consumption patterns might change based on water conservation practices that will intensify in more frequent drought conditions due to climate change (Erwin 2009). Analyzing consumer reaction to conservation measures during droughts will contribute to the discussion in improving water management practices, especially those during water shortages, going forward.

In this study I will characterize consumer water demand for the city of Oakland, California over the last 35 years and examine its relationship with climate change via weather data. The study will examine relationships of California's municipal water usage, which is 10% of California's total water consumption. Municipal demand, in terms of total consumption, in this area will be compared to local temperature. In particular, I expect that a relationship exists with temperature and water demand in Oakland, where water is provided by the East Bay Municipal Utilities District (EBMUD). I predict that in the period from 1975 to today, water demand has remained relatively stable with the population increase as a result of conservation measures, but water consumption significantly decreases in drought and high temperature conditions. I also predict that there is a positive relationship between temperature and water demand, representing seasonal effects.

METHODS

This study analyzed the effect of temperature on urban water demand in the city of Oakland. The study is based on secondary data from two data sets. EBMUD provided water consumption data, in thousands of gallons, and number of accounts for the entire city of Oakland. Water consumption was provided in three categories including household consumption, categorized “water”, as well as utility consumption, which consisted of “hydrant” and “fire” categories. Western Regional Climate Center (WRCC) provided temperature data, in degrees Fahrenheit, for the Oakland Museum site. Collectively, both data sets provided information from 1975 to 2009, a period of 35 years.

In order to simplify the study, I focused on total water consumption by Oakland by year, essentially adding the consumption categories of “water,” “hydrant,” and “fire.” This was done because household or “water” consumption accounts for the majority of municipal water usage and utilities play a very small role. Adding the three categories together, then, allowed my study to make a statement about the entire municipal water usage of Oakland. In the study, I determined the percentage of total consumption, as well as the mean and standard deviation of each water consumption category.

To determine the relationship between temperature and total water consumption in Oakland a scatter plot and statistical analysis also took place, to both visualize trends and find significance. A linear regression was conducted between total water consumption and temperature. Seasons were made a category within temperature, using traditional monthly definitions of seasons. My study defined spring to consist of the months March, April and May. Summer was limited to June, July and August. Autumn was characterized as September, October, and November, while winter was classified as December, January and February.

To further analyze seasonal differences in total water consumption in Oakland, a one-way ANOVA test was conducted. A pair-wise comparison (Tukey's test) was also conducted to see which seasons were significantly different from each other. A box and whisker plot was produced to visually show seasonal consumption trends.

The study conducted another one-way ANOVA test to determine statistical significance in differences in total water consumption in Oakland in drought and non-drought years. Drought conditions were defined by the California State government to be the periods of 1976-77, 1987-92 and 2007-2009 (Dracup & Vicuna 2008). A box and whisker plot was produced to visually show water consumption during drought and non-drought conditions, as well.

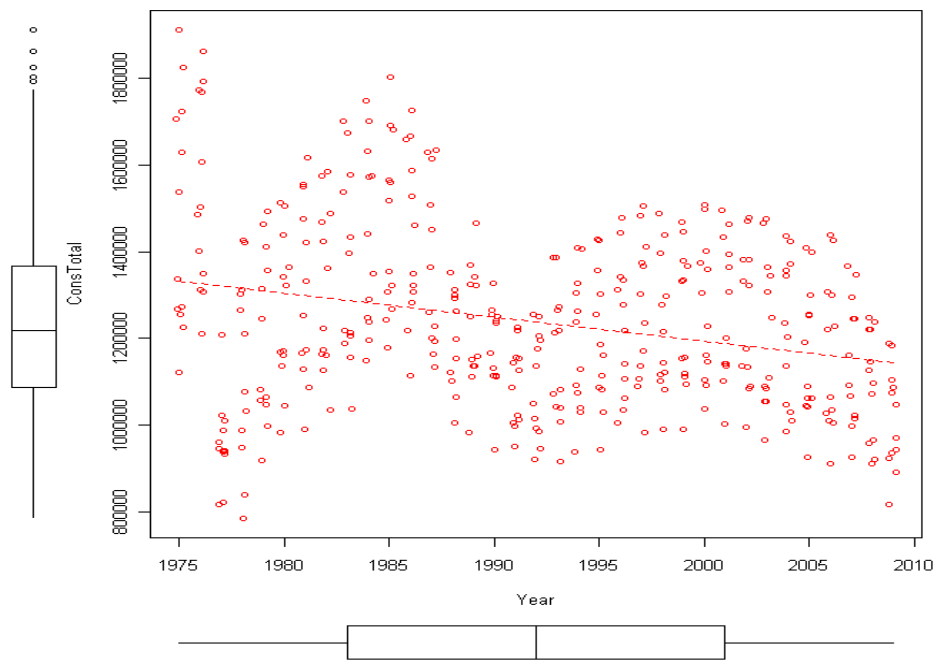
In order to visualize the historical relationship between water consumption and temperature a scatter plot was produced. Both variables are shown historically, from 1975 to 2009. Total water consumption by year is also provided in a unique chart because it proved relevant to my study. These methods address both the question and the hypothesis because they allow me to see just how temperature impacts consumer water demand over time. All statistical analyses were conducted to see the nature and strength of relationships and were done using the software R and R Commander via Microsoft Excel (R Development Team 2000) (Fox 2009).

RESULTS

My study only used total water consumption values for Oakland because that allowed the study to make a statement about all of the municipal water usage in Oakland. Most of the total usage, however, comes from household use which makes up 99.4%, with a standard deviation of approximately zero, of total water consumption. “Hydrant” (.4 ± .004%) and “fire” (.2 ± .002%) made up a very small portion of total municipal water consumption in Oakland.

To visualize the relationship between total water consumption in Oakland by year a scatter plot was produced, showing overall decreasing consumption. Figure 1, below, shows total consumption, in thousands of gallons of water by year. Each point on the graph represents monthly totals of consumption and thus there are 12 points for each year. A trend line is also provided within the plot, showing the downwards slope of consumption from 1975 to today, overall. Another important trend to note is the three major valleys in the plot, which all occur in drought years as defined by the California State government.

Oakland Water Consumption by Year

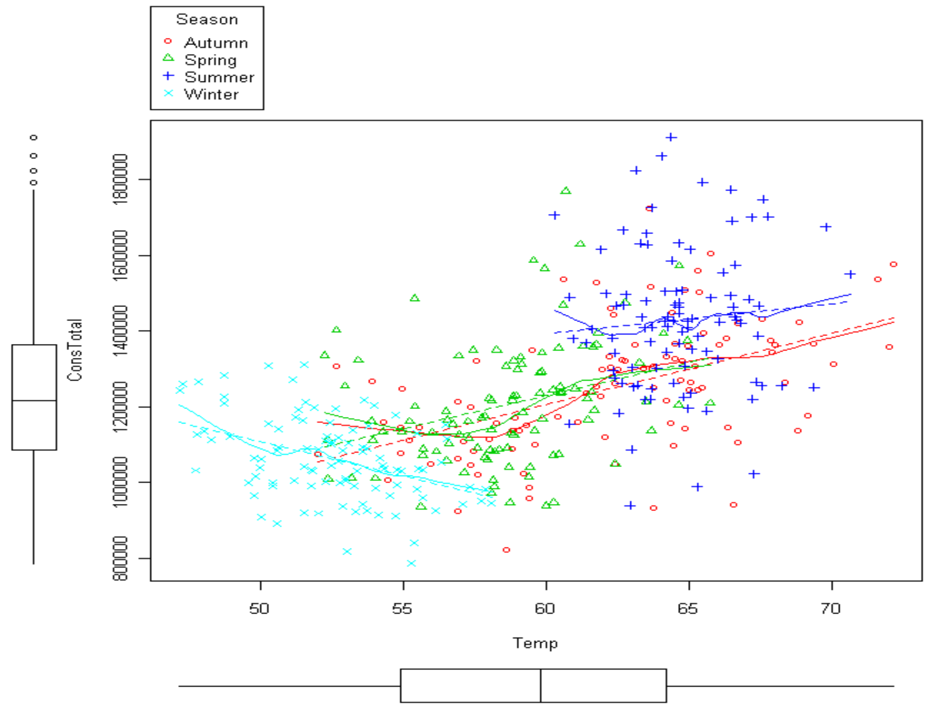


Source: EBMUD

Figure 1. Oakland Water Consumption (Total) by Year Scatter Plot

A linear regression, which was conducted between total water consumption and temperature, showed a highly significant relationship between variables. Statistical support explained this relationship, $R^2 = .35$, $F(1,393) = 212.7$, $p<.001$. Figure 2, below, shows this overall relationship between total water consumption, in thousands of gallons, and temperature in degrees Fahrenheit. The figure also separates out seasonal consumption by color, denoted in the legend. The strong significance between variables, shows that total water consumption increased with temperature in Oakland, as is shown visually in the chart below (Figure 2).

Oakland Water Consumption by Temperature

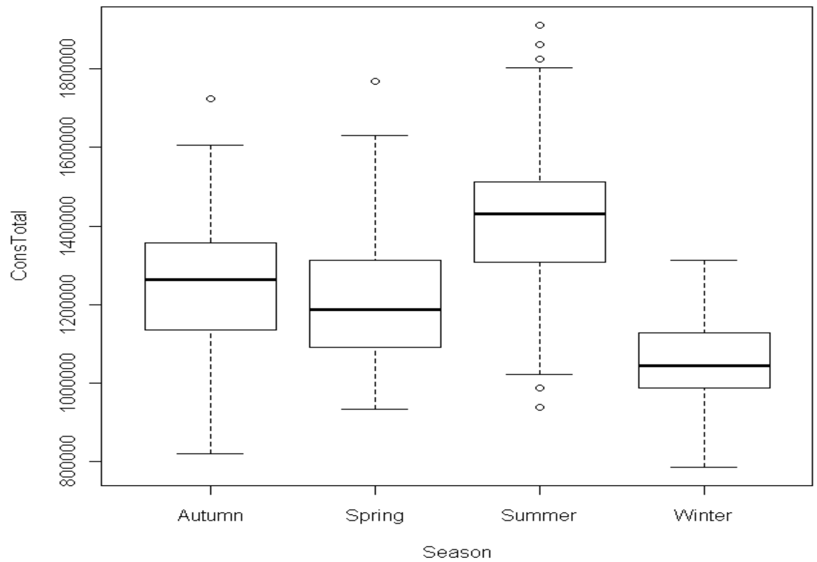


Sources: EBMUD, WRCC

Figure 2. Oakland Water Consumption (Total) by Temperature Scatter Plot

To further analyze seasonal differences in consumption, a one-way ANOVA test was conducted, which showed significant seasonal differences, overall. Figure 3, below, shows total consumption, in thousands of gallons, by season. The ANOVA revealed strong significance between seasons generally, $F(3, 416) = 102.09$, $p<.001$. A pair-wise comparison (Tukey's test) was also conducted to see which seasons were significantly different from each other. The comparison revealed that summer was significantly different from autumn and spring at a 95% confidence level. All of these trends are consistent visually with the box and whisker plot shown below (Figure 3), which also shows outliers, represented by circles.

Oakland Seasonal Water Consumption

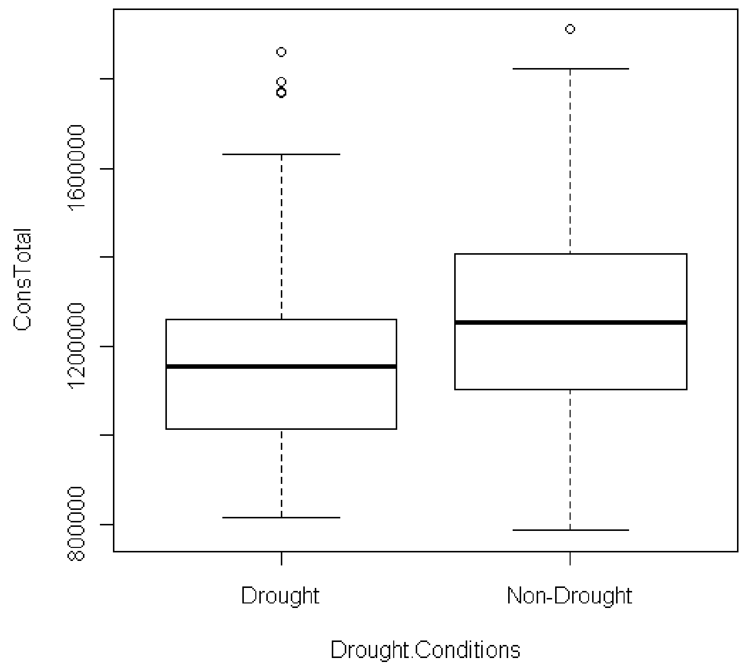


Sources: EBMUD, WRCC

Figure 3. Oakland Seasonal Water Consumption Box and Whisker Plot

The study conducted another one-way ANOVA test, which showed significant differences in consumption in drought and non-drought conditions, which were determined by the California State government. Statistical significance, $F(1,418) = 19.88$, $p < .001$, shows that water consumption was statistically different in times of drought versus times of non-drought. The box and whisker plot below (Figure 4), below, visually shows the same trends, with higher water consumption in non-drought conditions.

Oakland Water Consumption in Drought and Non-drought Conditions



Sources: EBMUD, WRCC

Figure 4. Oakland Water Consumption (Total) by Year

In order to visualize the historical relationship between water consumption and temperature a scatter plot was produced. The chart below (Figure 5) shows water consumption of Oakland in thousands of gallons (in monthly totals), as well as temperature, in degrees Fahrenheit. Both variables are shown by year since 1975 until 2009. Note the relationship between temperature and consumption and how that relationship varies over time. Once again, valleys in the consumption are shown coinciding with drought conditions. Historically, temperature has shown no significant change, over time, $R^2 = .0006$, $F(1, 393) = .23$, $p = .63$, in Oakland. Visually, temperature has remained consistent over this time period, as well.

Historical Water Consumption and Temperature of Oakland

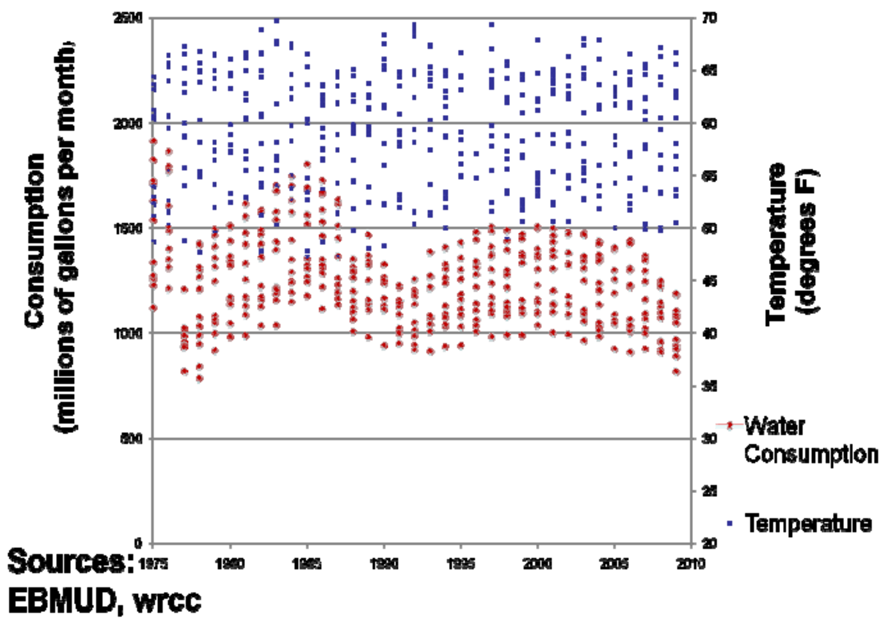


Figure 5. Oakland Water Consumption (Total) and Temperature by Year

DISCUSSION

My study questioned the impact of temperature on urban water consumption in Oakland. My study, under the assumption that temperature is a valid indicator of climate, aimed to provide insight on how water demand might change as a result of climate change. Overall, I expected a stable water consumption trend over this period of time. I hypothesized that water consumption would increase in drought or high temperature conditions, suggesting a positive relationship between temperature and water demand. Seasonally, I expected the highest water consumption to occur in the summer months.

The study focused on total water consumption by Oakland by year, essentially adding the consumption categories of "water," "hydrant," and "fire." This was done because household or "water" consumption accounts for the majority of municipal water usage and utilities play a very small role. Focusing on the total consumption rates allowed my study to look at all of municipal water usage within Oakland. Looking at the categories separately, provided consistent results with those shown in my study, but are not provided here.

The relationship between temperature and total water consumption in Oakland shows an overall increasing demand for water as temperature increases. Seasonally, the demand for water has been greatest during the summer month, by far (Dracup & Vicuna 2006). The variability of the autumn season is due to the fact of the Mediterranean Climate pattern in California, where September is often the hottest month, but is characterized as autumn in a traditional definition of seasons (Gasith & Resh 1999). Winter usage has been the lowest, likely due to a lower preference of water for gardening and showers, for example (Tarlock, 1991). My hypothesis for a seasonal preference of water was proven to be correct.

The study also found statistically significant differences in total water consumption in Oakland in drought and non-drought years. Consumption has been highest in non-drought years, reflecting policy and pricing changes that occur during drought years (Nieswiadomy, 1992). These changes influence human behavior and force people to use less in times of water scarcity (Betchart et al. 1981) (Weber 1989). My hypothesis of lower water consumption during drought conditions was also correct.

Overall, the results showed a decreasing trend in water consumption over the time period of the study, while temperature has remained relatively stable. My hypothesis of a consistent water consumption pattern was incorrect. Also, climate remained consistent over this time period, something that my study did not expect to see.

My results, within the broader literature, show that temperature does play a role in consumer demand, especially when considering seasonal and drought or non-drought conditions. The variability of the impacts, however, implies external forces are involved, meaning a relationship between water and temperature is not fully capturing the complex interactions of water consumption (Betchart et al. 1981). The fact that my study shows a decrease in water consumption as temperatures rise suggests that pricing and policy likely play a role in these dynamics, an aspect that my study does consider, albeit indirectly (Mukheibir 2008). During higher temperatures, water prices rise due to stricter policies and consumption drops, which is evident in this study (Nieswiadomy, 1992).

Given the existing limitations, as well as how my study fits into the larger academic context, there are still many important concepts to be drawn out from my study, as well as future research directions. My study suggests that water consumption is not dependant on only temperature (Browning-Aiken et al. 2007). Human behavior, in terms of water demand, is also subject to price and a negative relationship exists between price and consumption (Ruijis et al. 2008). Based on my study, this suggests a positive relationship between temperature and conservation efforts, in terms of price (Ruth et al. 2007). This means that water management improvement efforts will be best served by targeting consumer behavior via price and policy, rather than attempting to increase water supply (Lee & Warren 1981).

Although my study indeed shows a significant and relevant relationship between temperature and consumption, there are confounding factors as well as weaknesses in the study design that limit the strength of my findings. As stated earlier, price and conservation policies are major contributors to consumer water consumption (Yates et al. 2008). This suggests that temperature is not necessarily the driving force that determines consumption (Islam et al. 2005). A better study would look at pricing and policy changes over the years and relate that to temperature (Walters & Young 1994). This would give a more comprehensive overlay of water consumption interactions. In addition, a larger sample size, covering more consumer areas, as well as a longer period of time would be optimal. Given the time constraints, however, this project still provides a meaningful addition into the current literature.

This study serves as a step towards understanding how to best manage water in a climate-influenced future. Understanding human water consumption behavior is essential and coming up with policies that target behavior can maximize water conservation (Mullen & Yu 2009). This is a promising development and provides hope that water security will not be an issue going forward (Erwin 2009). My study shows that temperature is one of many factors that influence consumption, but also suggests that the current water consumption is not at minimum requirement levels (Georgakakos et al. 2005) Basically, consumers are using more water than they actually need, at least in times where conservation efforts are minimal (Jorgenson et al. 2009). Improving water usage behavior and long-term conservation will keep water consumption at lower levels and make water scarcity a minimal issue, going forward (Dvorak et al. 1996).

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