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Uncovering the Influence of Household Sociodemographic and Behavioral Characteristics on Summer Water Consumption in the Portland Metropolitan Area

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Abstract
As urban areas continue to expand, sustainable urban water resource management has become an important issue in green and sustainable city planning. Using single-family residential (SFR) household survey, we identified the determinants of household summer daily water consumption from 2000 to 2005 in Portland, Oregon. The multiple regression results show that approximately 41% of variations in SFR water consumption is explained by average building size, household attitude to water conservation, community engagement of household, and presence of native plants in the garden. The multi-level modeling results show that household attitude to water conservation is an important predictor of SFR water consumption within and between neighborhoods, while household mean income is not a good predictor of water consumption at both levels. The findings suggest the roles of community program for efficient urban water resource management. Our results have important implications for sustainable urban water resource management and land use planning as they relate to water use behavior in urban areas.

Keywords
water consumption, urban water, land use, behavior, multi-level analysis

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1. INTRODUCTION

As urban populations continuously grow and climate change stresses urban water resource systems, there is a growing interest in studying the determinants of urban water consumption using spatially-explicit data (House-Peters and Chang 2011; Wentz and Gober 2007). Some previous studies showed that urban forms are tightly coupled with urban water consumption (Chang et al. 2010; Gober et al. 2013; House-Peters et al. 2010), while others pointed out the importance of socioeconomic and behavioral factors that affect household water consumption (Harden 2012). Additionally, like any geospatial analysis, the determinants of water consumption are different depending on the scale of analysis (Ouyang 2013).

Differences in water demand and consumption might exist as they relate to urban forms, so it is important to understand the relationship between density of urban development and water consumption in order to project future water demand and to plan efficient water management programs in major metropolitan areas. Agthe and Billings (2002) showed a positive correlation between physical facilities, such as swimming pools, and water consumption, in apartments in their Arizona case study. Similarly, Wentz and Gober (2007) showed that the presence of pool increases water consumption at the census track level in Phoenix, Arizona. Chang et al. (2010) and House-Peters et al. (2010) reported higher water consumption rates in sparsely developed suburban Portland and Hillsboro, Oregon, respectively. In a follow-up study, Breyer et al. (2012) showed that higher temperature sensitivity (defined as the response of area's water consumption to temperature increase) areas are located in relatively newly developed suburban Portland. Zhang and Brown (2005) found diverse housing typologies have various water consumption patterns in Beijing and Tianjin.

According to Randolph and Troy (2008), the contexts of the socio-demographic factors of households should be understood as an important element in water use studies. Arbues and Villanua (2006) reviewed the influence of family size and education level on water consumption in Zaragoza, Spain. Moreover, they argued that temperature and household size are significant variables for explaining seasonal water consumption, but outdoor water uses are not a significant factor because many people go away for their vacation during summer (Arbues and Villanua, 2006). Tinker et al. (2004) reviewed that weather and economic construction factors such as lot size, house building size, and market value on water consumption level in the area of Austin, Texas. In their research, variability in water consumption was significantly related to economic factors, including outdoor house water facilities and lot size. In the Portland metro area, high-income neighborhoods are typically located in relatively new suburban areas, so socio-demographic variables appear to covary with building structural variables (Breyer et al. 2012; Chang et al. 2010; House-Peters, 2010).

Hassell and Cary (2007) argued that community activities based on knowledge with education programs can be a significant factor that influences water consumption. More educated individual tends to have open attitude to take part in environmental conservation activities. Moreover, community education programs can influence each individual's water consumption pattern. Cheruseril (2007) argues that water consumption is strongly positively associated with education level, household size, and property types in the case of Melbourne. Similarly, Campbell, Johnson, and Larson (2004) also found that water consumption can be affected by community education programs as well as water price and policy in Phoenix, AZ. Cheruseril (2007) and Dube and Van der Zaag (2003) explain that different income levels have distinctive water consumption patterns in the city of Masvingo and Metropolitan Melbourne, respectively.

Since water issues arise from human behavior (Corral-Verdugo et al. 2008), investigation of water conservation behavior is needed in water use studies. Corral-Verdugo et al. (2008) review the variables such as watering plants at night and reducing shower time (sustainable behavior) in their questionnaire. They found the belief that humans interfere with the natural balance is associated with sustainable water use. Similarly, households with positive environmental attitudes use less water for lawan irrigation in Australia (Fielding et al. 2012; Willis et al. 2011). (By relating housing construction data with water use patterns, Tinker et al. (2004) found that landscaping with drought-tolerant vegetation correlated with more extensive permeable surfaces and smaller lot sizes. However, Harlan et al. (2009) found that while household income and lot size had positive relationships with water use, attitudes were not significantly associated with water use in Phoenix, Arizona. Water consumption behavior in Portland is most influenced by rapid urbanization and development, educational attainment, policy tools, and individual attitudes concerning water resources conservation (Campbell et al., 2004).

Randolph and Troy (2008) argue that, while water demand mitigation strategies have had some success, domestic consumption remains high in the case of Sydney, Australia, and attitudes of households continue to affect water consumption patterns and in turn, feedback on ecosystems. Sauri (2013) states that outdoor water use of households in North American cities and European cities is associated with behavioral resource use patterns, which arise from individual beliefs and values. According to Sauri (2013), American cities tend to use relatively more water outdoors than European cities due to different economic, behavioral, technological, and educational contexts. In particular, household behavioral responses to water conservation and water management also may explain differences in water consumption rates. Also, Hurlimann (2008) argues that community activities and attitude based on individual behavior toward water use can influence water consumption pattern.

Sauri (2003) argues that water consumption can be explained by socio-demographic and land use patterns at different scales. Moreover, fixed effects from economic construction variables such as lot size, house size, and water facilities can indicate how much they are associated with household water consumption. However, Ouyang et al. (2013) reported no significant differences in the determinants of urban water consumption at both household and census track scales. They identified household size, household income, house age, pool size, irrigable lot size, precipitation, and temperature as important factors affecting urban water consumption at both spatial scales in the study of Phoenix, Arizona.

The modifiable areal unit problem (MAUP) provides a key for understanding analytical different results from this scale effect (Wong 2009). Tomoki (1999) argues that the size and boundaries of neighborhoods influence more or less the aggregated value. According to Kwan (2012), we need to consider this MAUP issue in studying differences among aggregated groups or units. Similarly, we hypothesize that we could observe the scale effects in understanding water use patterns by using regression analysis at the household and neighborhood levels. Hox (2002) argues that social science studies motivate to investigate and search for defining the relationship between individual and society in each scale or level of a hierarchical structure. In other words, comparative research including more than one level based on interaction between individual variables and group variables can contribute to understand water consumption pattern at larger spatial scale (Stoler et al., 2013).

However, not many previous studies used building structural variables, household socio-demographic characteristics and behavior for explaining water consumption patterns across different scales (House-Peters and Chang 2011). Considering these factors, this research, using household questionnaires, examined the relationship among the level of household water consumption, socio-demographic information, water use behavior, and specific water usage, such as outdoor water use during the summer season at both household and neighborhood scales.

Research Questions

(1) What factors of households and building structural variables are associated with household water consumption pattern?
(2) How do the determinants of urban water consumption vary at the individual household level and the neighborhood level?
(3) How differently does water conservation behavior influence household water consumption among selective neighborhoods in Portland?

2. STUDY AREA

Portland is located in northwestern Oregon at the confluence of the Columbia and Willamette rivers. Located in the marine west coast climatic region, Portland has a distinct seasonal pattern of precipitation and water availability (Chang, 2007). Winter rainfall replenishes aquifers and supplies water for various summer uses. Portland obtains its water from Bull Run reservoirs, a pristine source of drinking water that is protected from land development (Portland Water Bureau 2014). According to the 2010 Census data, Portland was Oregon's most populous city, with its population of 583,776. Portland is often quoted and awarded as the "Greenest City” in America. According to the Environmental News (2008), Portland, Oregon is the best city representing green regional planning.

Portland uses a distinct urban system, called the Urban Growth Boundary (UGB), to limit the expansion of the metropolitan area and minimize the environmental impacts of urban growth in surrounding metropolitan areas. Accordingly, city planners of Portland have been focusing on green and environmental issues in their policy and related urban affairs. The UGB and efforts by the Portland city planners limit access to water, sewage, and telecommunication utilities. People in Portland had to adjust and reduce the resource consumption under the density pressure resulting from limited urban space. As a result, Portland has become much denser than Vancouver, Washington, a city located across the Columbia River in the Portland-Vancouver metropolitan area (Chang et al. 2014).

According to Abbott (2001), the neighborhood movement based upon active community engagement under the UGB has made Portlanders' lifestyle democratic, environmentally conscious, and politically liberal since the 1970s. Even though Portland is well known for a green city, there are some disadvantages associated with rapid population growth. Some suburban water providers in the Portland metropolitan areas are facing potential water resource issues stemming from climate change and population growth (Larson et al. 2013). The perceived vulnerability has big implications for future water resource management and conservation in the area. Thus, studying the water consumption behavior of Portlanders is timely and important for understanding people's behavior of this greenest city as a role model, for providing effective suggestions to other cities that pursue to be green.

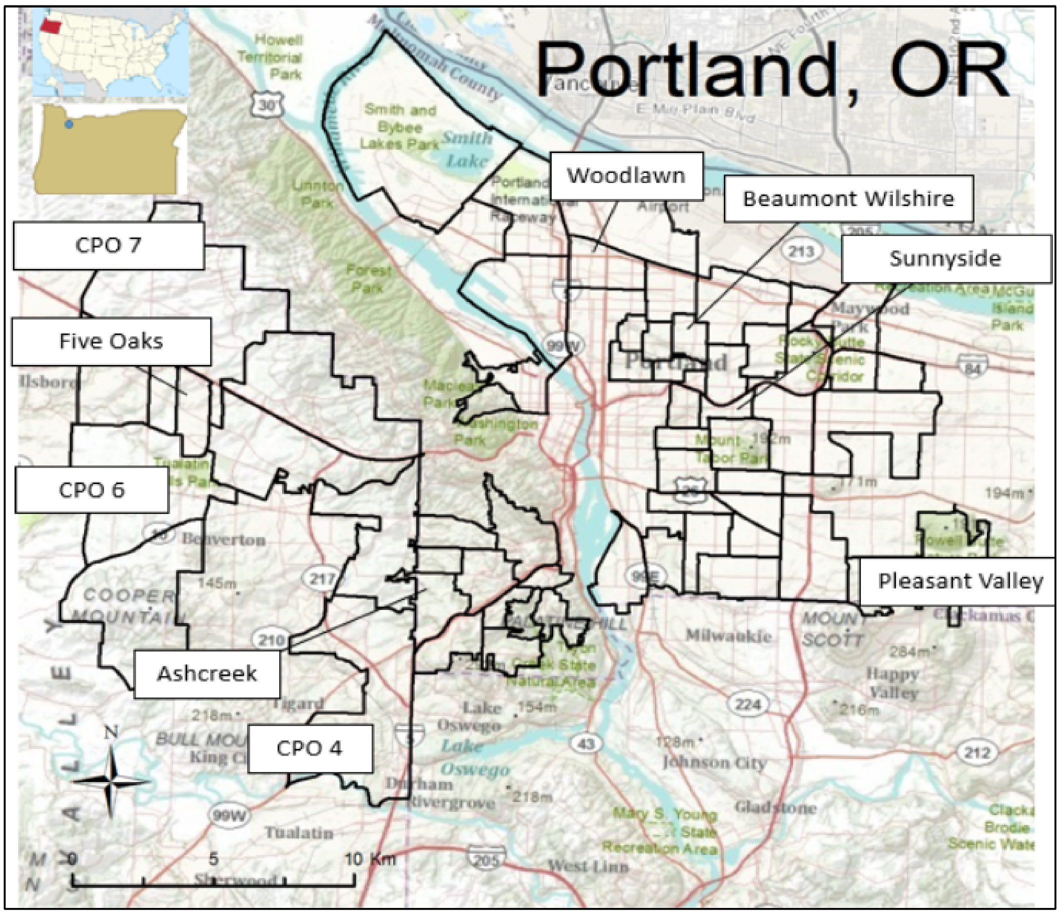

Figure 1. Schematized RLIS (Regional Land Information System) neighborhood boundaries studied in this research in the Portland metropolitan area

3. DATA

Survey data was collected from the water providing service areas - Portland Water Bureau (PWB) and Tualatin Valley Water District (TVWD) - by researchers at Portland State University. The study sample population was drawn from the 664 households that had participated in the customer demand monitoring study between 2000 and 2007. PWB and TVWD provided daily water consumption data of these 664 households. Survey questionnaires were mailed to all these customers, and 175 surveys were returned. From which 13 surveys were discarded as their responses were either incomplete or the records did not match with the current address. Water consumption levels, outdoor water use, indoor water use, household attitudes, and the demographics of each household were collected from the survey responses. In particular, many case studies on water consumption have introduced socio-demographics as important predictors of water consumption (Agthe and Billings, 1997; Baumann, Boland, and Hanemann, 1998; Duke, Ehemann, and Mackenzie, 2002; Foster and Beattie, 1981; Hanke and de Mare, 1982; Hoffman, Nauges and Thomas, 2003; March and Sauri, 2010; Martinez-Expineira, 2003; Opaluch, 1982; Stocker and Rothfeder, 2014; Worthington, and Higgs, 2006).

Also, we assume that data availability across the sampled area may have been limited by specific constraints or individual events in each household, resulting in randomly fluctuating values within the same neighborhood. Thus, we aggregated household water use to RLIS (Regional Land Information System) neighborhood scale. RLIS neighborhood boundary, provided by the Portland Metro regional government, represents somewhat similar sociodemographic, building structural characteristics, and political views in Portland. We collected and aggregated single family residential (SFR) daily water use records between 2000 and 2005 to the neighborhood scale. Some missing or suspicious zero values in the water use records were removed for analysis.

In order to collect appropriate information that drives SFR water use, we rely on previous studies concerning water consumption at household and community levels summarized in Table 1. These studies identified some common predictors of water consumption at different levels. Guhathakurta and Gober (2010), for example, studied the sensitivity of SFR water use to temperature change in Phoenix, AZ, and found that landscaping practices can induce temperature-sensitive summer outdoor water use in high income Phoenix census tracks. March and Sauri (2010) and Domene and Sauri (2006) examined the relevance of physical structure types and size as well as socio-demographic factors through OLS regression models in Barcelona, Spain. Similarly, Chang et al. (2010) and Wentz and Gober (2007) found that residential water consumption can be largely explained by building density, age, and size at the census track and census block groups in Phoenix and Portland, respectively. Polebitski and Palmer (2010) identified building and lot sizes, maximum temperature, and restrictions are significant predictors of summer water use in Seattle, Washington. Sohn (2011) investigated the relationship between urban density and city and County water use in Southeastern US. While physical environmental variables themselves are not good predictors, once they are combined with clustered heavy water use areas, they became significant predictors of water use. These studies suggest that neighborhood effects need to be more closely examined.

Table 1. Illustrative case studies for urban residential water consumption

Author(s)(Year)	Study Area	Methods	Variables	Main Finding
Domene and Sauri (2006)	Barcelona, Spain	OLS	Housing type, building size, price of water, consumer behavior index	Analysis about behavioral patterns with regard to water use, water consumption in relation to household and socioeconomic characteristics
Wentz and Gober (2007)	Phoenix, AZ	Geographically weighted regression (GWR)	Water consumption, percentage of pool, average lot size, percent residential area of mesic landscaping, average household size	Effects of household and housing characteristics on residential water consumption at the census track
Chang, Parandvash, and Shandas (2010)	Portland, OR	OLS, Spatial regression, piecewise regression	Water consumption per household, building size, density, age of building	Residential water consumption explained by building density, age, and size for recognizing water demand framework (census block group)
Guhathakurta and Gober (2010)	Phoenix, AZ	Ordinary least squares regression (OLS)	Temperature, vegetation	Strategy for relieving heat island effects, water per single family unit
March and Sauri (2010)	Barcelona, Spain	OLS	Domestic water consumption, income, household size, age, population growth, urban model, rainfall, temperature	Influence of demographic, socioeconomic, and climatic factors on domestic water consumption
Polebitski and Palmer (2010)	Seattle, Washington	Regression (pooled, fixed effects and random effects)	Density, building size, lot size, household size, income, price, temperature, precipitation, restrictions	Significant predictors vary by months and models
Sohn (2011)	Southeastern Area, United States	Spatial regression	Water price, annual precipitation, average July temperature, humidity, density	Urban density and water price are associated with water use.

4. METHODS

We created a statistical model of water consumption patterns at the household level and the neighborhood level, because the determinants of water consumption might vary over different spatial scales (Ouyang et al., 2013). The analysis used multiple linear regression models with the average daily household water consumption as the dependent variable and socio-demographic and structural data, such as lot size, income, education level, and household size, as the independent variables. Additionally, we examined if the variables of household are associated with water consumption at the RLIS neighborhood level.

4.1 Data Compilation

4.1.1 Daily summer water consumption

We calculated average summer daily water consumption from 2000 through 2005 for the 162 households that returned our survey. Summer months (from June to September) are hypothesized to have significant outdoor water uses. The average daily water consumption during summer between 2000 and 2005 was 319.37 gallons (1208.95 liters) per household in the Portland Metropolitan Area. Larson (2010) and Arbues and Villanua (2006) have stated that socio-demographic data and individual behavior are associated with water consumption patterns. Thus, our independent variables include attitude to water conservation, environmental perception, and demographic information. These data sets include the socio-demographic information of each individual household, such as education, building size, gardening characteristics, water usage behaviors, income level, community responsibility, and environmental responsibility.

4.1.2 Physical features

We used lot size, building size, number of bathrooms, and built year as physical features representing the characteristic of each household. Wentz and Gober (2007) examined the building size and lot size as variables to water consumption in Pheonix, AZ. We used RLIS parcel level data that include lot size, building size, and built year as they provide the most accurate information about each household's.

4.1.3 Attitude to water resource

The attitude of household to water resource can have significant influence on water consumption. We examined neighbors' environmental attitudes and planting preference of households that were collected from the survey. These attitudes directly reflect the interest to join community water conservation programs as well as individual water saving efforts.

4.1.4 Neighborhood-level socioeconomic composition

We evaluated neighborhood level socio-economic composition on water consumption based on 21 RLIS (Regional Land Information System) units and 26 zip code units because neighborhood data may reveal different determinants of water consumption than those measured at the individual household level. Also, analysis using data aggregated by zip code differs from analysis using data aggregated by RLIS neighborhood. This research focused on studying RLIS groups only. Thus, we aimed to study how integrated group data are associated with water consumption and what the difference between household level and RLIS neighborhood level exists.

4.2 Statistical Analysis

We used a linear mixed effects model for survey results and water use data with SPSS 21. Prior to developing the mixed model, we performed a multiple linear regression (OLS) analysis in order to find the structural relationships between the dependent variable, daily average water consumption per household (Baumann, 1998), and the independent variables:. In general, residential water use is a function of price, household income, and other housing, climate, and social characteristics in the selected areas (Domene and Sauri, 2006). The independent variables were selected after we studied the literature review conducted by other scholars, as stated above. The conceptual model is as follows:

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots\ldots \beta_n X_n + e_i \quad (1)$$

In this equation, Y_i is the average daily water consumption at the household level (gallons/household/day); X_i are independent variables from the survey and the socio-demographic data.

The mixed-effect modelling procedure explains relationships between household water consumption in summer and RLIS neighborhood characteristics. This regression modeling is used to specify a hierarchical system of regression equations that take advantage of the clustered data structure (Heck & Thomas, 2009). First, our research question focuses on whether household water consumption level during summer season varies across RLIS neighborhood groups. Second, we examine whether the effects of household characteristics in each RLIS neighborhood influence water consumption. Third, we investigate whether structures related to water (i.e., watering with planned irrigation system) and community activities (i.e., community water conservation program) affect summer outdoor water consumption. Therefore, we design a mixed-effect statistical model with two levels to investigate (1) a randomly varying intercept and, (2) randomly varying slope model. In this regression analysis, we use three equations: a within-group (individual level) equation, a between-groups intercept equation, and a between-groups slope equation. For each individual household *i* in RLIS neighborhood *j*, the conceptual model of individual-level Random Intercept Model can be as follows:

$$Y_{ij} = \beta_{0j} + \beta_1 X_{ij} + e_{ij} \quad (2)$$

where β_{0j} is the intercept and β_1 is the regression coefficient, e_{ij} represents variation in estimating individual household characteristics within groups. First, this research considered independent variables and water use at the individual household neighborhood level. Next, we analyzed RLIS neighborhood-grouped characteristics based upon the individual household variables to explain the variability in intercepts across RLIS neighborhood groups. In our case, we hypothesize that individual household variables and aggregated households characteristics at the RLIS neighborhood (i.e. average income level of each RLIS neighborhood) will impact the remaining variability in water consumption of household unit between and within the RLIS neighborhoods.

$$\beta_{0j} = \gamma_{00} + u_{0j} \tag{3}$$

$$\beta_{0j} = \gamma_{10} + u_{1j} \tag{4}$$

Equation 3 implies that variation in the intercepts can be described by γ_{00}, or grand mean, and a random parameter capturing variation in individual neighborhood means (u_{0j}) from the grand mean. Equation 4 implies that a within-neighborhood slope can also be examined as randomly varying across neighborhoods in the sample. In addition, equation 4 also explains that variability in the slopes can be described by a neighborhood-level average slope coefficient γ_{10} from the grand mean because the slope is considered to be randomly varying across neighborhoods. The corresponding test of significance for each parameter will be based on the number of neighborhoods in the sample. Therefore, the linear regression model with two levels provides an estimated mean water use for all RLIS neighborhoods. It also provides a partitioning of the variance between level 1 and level 2. Altogether, there are three effects to estimate: the intercept, the between-RLIS neighborhood variation in intercepts (u_{0j}), and the variation in individual household water use within RLIS neighborhoods (e_{ij}).

5. RESULTS AND DISCUSSIONS

According to WaterSense under EPA (2014), annually outdoor water usage accounts for the highest proportion (30%) of total daily water use in American households. In our research, there is a significant correlation between attitude toward yard maintenance and the household water consumption Household variables at the neighborhood scale affected daily household water consumption. Building size and individual preference of planting and gardening seem to have a major effect on water consumption. Regarding household educational level, the results indicated no significant relationship. In other words, education level was not a good predictor in determining water use pattern in Portland, though previous studies such as Sauri (2013) and Arbues and Villanua (2006) showed significant positive relationships between income and water use. While we had expected those with a higher education to be more concerned with conservation, education level alone may not explain the majority of the variation in water use. In addition, household income was not a good indicator of water consumption at both household and neighborhood levels. According to previous research on domestic water use, low-income groups usually shower fewer times per week than do high-income groups (Domene and Sauri, 2006). Of course, education level also influences income level, which might be associated with the size of properties, so it is not certain how much household income impacts the water use in our research.

5.1 RESULTS OF OLS REGRESSION ANALYSIS (HOUSEHOLD LEVEL)

Table 2 shows the summary statistics of households in the survey. The mean household water consumption is lower than most other North American cities (Sauri 2013) and Australian cities, while it is somewhat higher than some European cities and Asian cities (Praskievicz and Chang 2009). This wide spread of water consumption across different households suggests that different drivers might explain the variation of water use in different local contexts.

Table 2. Summary statistics of daily summer outdoor water consumption of individual households in Portland (unit: gallons per day)

Variable	Minimum	Maximum	Mean	Standard Deviation
Water consumption	34.16 (129.31)	1267.00 (4796.12)	319.33 (1208.80)	212.73 (805.27)

*Numbers in the parentheses are in liters.

The OLS regression model summary in Table 3 gives a coefficient of determination (R-Square) value of 0.412, meaning that the independent variables mentioned above account for 41.2% of the variation in the household water consumption in our study area. While our model explains less than half of the variation, compared to other previous studies at the same scale (e.g., Sauri 2003), this is not too low. It is expected that survey responses reflect individual household characteristics and water use behaviors, so the majority of variations cannot simply explained by a few predictors. Our OLS regression equation is below:

Water use = 113.65 – 39.72 (Native plants) + 0.12 (Building size) + 0.07 (Lot size) + 39.64 (Neighbor's opinions) – 27.99 (Importance of lawn) + 35.457 (Maintenance of property) -48.53 (Responsibility to conserve water in community solidarity)

We found physical features such as building size, % native plants, and lot size are the most significant predictors of SFR water use. Community responsibility and attitude are the next significant parameters affecting water use in Portland during the summer season (see Table 3). The community responsibility parameters can provide potential and sustainable water conservation program at the community level. The variables of individual attitude indicate how much they agree to each environmental issue (1=strongly disagree and 5=strongly agree). Also, the questions on community responsibility were designed in five-point likert scale (1=strongly disagree and 5=strongly agree). These question sets were used to investigate correlations between individual attitudes toward neighborhood responsibility or pressure as they relate to water use patterns.

Table 3. Factors affecting household summer water consumption, Portland

	Variable	B	Beta	t	P	VIF
	(Constant)	113.646		1.076	0.284	
Physical Features	Native plants	-39.722	-0.240	-3.279	0.001***	1.157
	Building size (square meter)	0.118	0.393	5.682	0.000***	1.033
	Lot Size (square meter)	0.071	0.232	3.270	0.001***	1.089
Attitude	Neighbor's opinions are important	39.643	0.203	2.669	0.009***	1.254
	Lawn is important (Larger is better)	-27.993	-0.143	-1.984	0.049**	1.115
Community Responsibility	Well-maintained and well-manicured lawn improves prestige, as well as home value	35.457	0.182	2.496	0.014**	1.148
	It is my responsibility to conserve water by choosing to plant water-efficient vegetation	-48.533	-0.208	-2.859	0.005***	1.147

Note: N = 157 (162), **p < 0.05, ***p < 0.01

5.2 Results of OLS Regression Analysis (Neighborhood Level)

As shown in Figure 2, household water consumption at the RLIS neighborhood scale shows two interesting spatial patterns. First, there is a distinct east and west divide across the Willamette River. East Portland neighborhoods show lower levels of outdoor water use, while west Portland neighborhoods show the opposite. The water in the westside of the town is primarily provided by the Tualatin Valley Water District, while the water in the east side is mostly supplied by the Portland Water Bureau. The westside is typically characterized by relatively newer big houses while the eastside is denser and older. Such building structural variables affect the water consumption at the neighborhood scale.

Second, there exists a spatial gradient from inner neighborhoods to suburban neighborhoods. While inner neighborhoods typically have lower levels of summer water consumption, suburban neighborhoods exhibit higher levels of summer water use. These neighborhoods coincide with relatively newer homes with big lots, while inner neighborhoods are old and dense. These building age and density characteristics are strongly associated with water use in Portland as reported in previous studies (Breyer and Chang 2014; Chang et al. 2010). For example, the CPO7 neighborhood (Sommerset West Elmonica NS) in the western Portland metro has the highest summer outdoor water use (574.82 gallons per day (2175.93 liters)), more than three times of water use compared to the BW (Beaumont-Whilshire) neighborhood in northeast Portland.

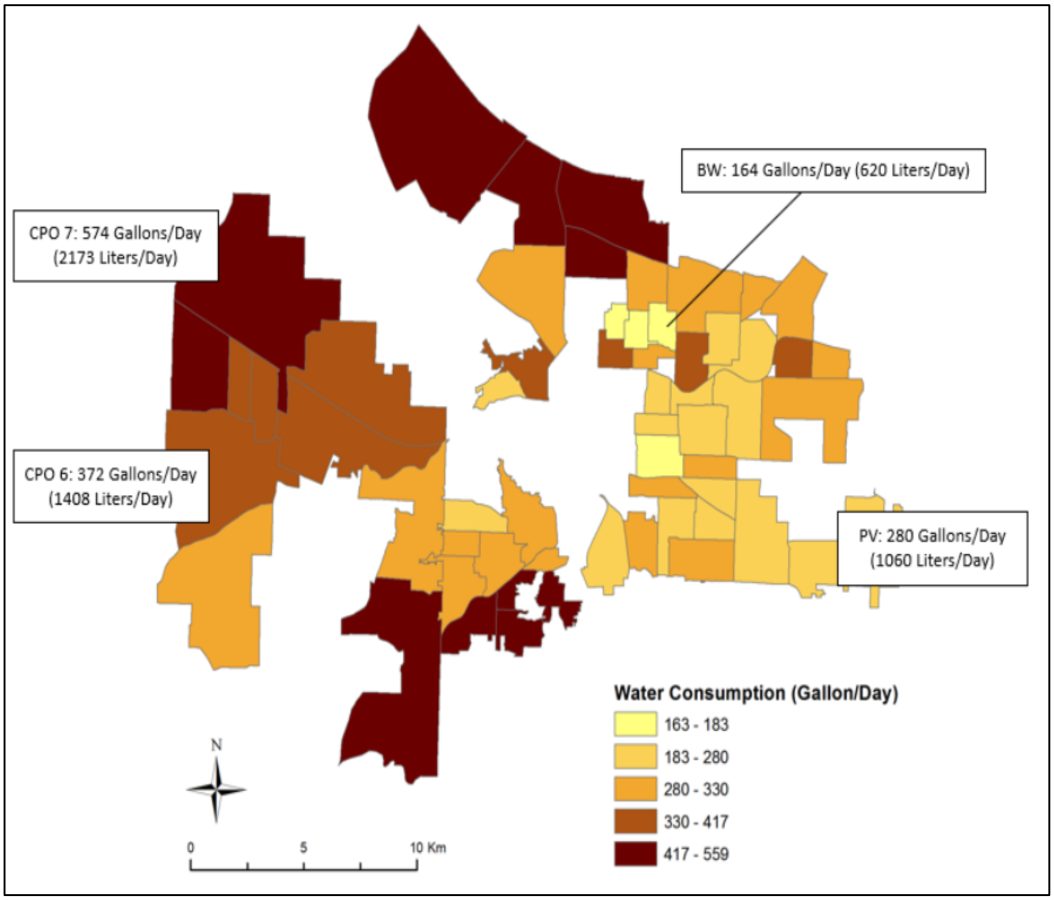

Figure 2. Household Summer Water Consumption at the RLIS Neighborhood level

As reported in Table 4, seven of 12 independent variables are statistically significant in the mixed-effects model. Table 5 describes the fixed effect estimates. Regarding the RLIS neighborhood level predictors, controlling for the other predictors in the model, we first find that community responsibility (interest about joining community water conservation program) of each household between the RLIS neighborhood group affects water consumption during the summer season in Portland (Wald $Z = 2.029, p < 0.05$). Also, people in the households believed that their responsibility to conserve water could influence gardening and planting in their garden. In other words, they would choose water-efficient vegetation and plants for environmental water management at the RLIS neighborhood level ($p < 0.05$).

Parcel level physical characteristics (e.g. lot size) are significant predictors of water use within and between RLIS neighborhood groups ($p < 0.05$). As shown in Figure 3, property size is particularly high in southwestern neighborhoods that correspond to higher levels of water use in summer (see Figure 2). In addition, the linear mixed effects model shows that household income level is highly associated with summer outdoor watering at the RLIS neighborhood level ($p < 0.01$). Other yard characteristics such as

% native plants, % ground cover, and % hardscapes are significant predictors of outdoor water use. As % native plants and ground covers increase, outdoor water consumption decline. Surprisingly, % lawn grass is not a good predictor of water use in the mixed effects model. This may be associated with the fact that many Portland residents do not necessarily water their lawns as summer progresses (Chang et al. 2014).

Other attitude variables regarding water conservation are significant predictors of outdoor water use at the RLIS neighborhood scale. First, households' inclination to community responsibility is negatively associated with water use. Similarly, interest in water resource conservation decreased water consumption level. The more concern residents had about the water shortage issue during summer, the less water they consumed.

Table 4. Estimates of Fixed Effects

Parameter	Estimate	df	T	Sig.
Intercept	441.47	128.85	4.30	0.000
Community involvement in a water conservation program	-40.67	120.31	-2.33	0.021**
Responsibility to conserve water by choosing water-efficient vegetation.	-43.49	121.80	-2.53	0.013**
Lot size	.065	125.38	2.86	0.005***
Mean Household Income	14.84	126.44	1.77	0.079*
Frequency of irrigation	23.75	123.98	1.43	0.156
% Native planting in the yard	-33.20	124.88	-2.48	0.014**
% Lawn/turf grass in the front yard	7.20	122.94	1.10	0.273
% Ground covers in the back yard (plants, bark dust)	-34.24	121.46	-2.86	0.005***
% Hardscapes in the back yard (decks, patios, pathways)	22.16	124.22	2.61	0.010**
% Bare soil in the back yard	27.93	119.03	1.74	0.84

Dependent Variable: Summer Water Consumption in Gallons; * significant at the 10% level; ** significant at the 5% level; *** significant at the 1% level

In addition, we assumed that watering system in households would be highly associated with summer outdoor water use at the RLIS neighborhood level. However, watering features such as automatic and non-automatic irrigation systems were not significant variables affecting outdoor water use. Moreover, mean household education level in the RLIS neighborhood group did not have significant association with summer outdoor water consumption changes between and within RLIS groups.

Table 5. Estimates of Covariance Parameters

Parameter	Estimate	Std. Error	Wald Z	Sig.
Residual	6568.18	876.15	7.50	0.000***
Intercept [subject = Variance RLIS Neighborhood]	1692.74	834.18	2.029	0.033**

Dependent Variable: Summer Water Consumption in Gallons.

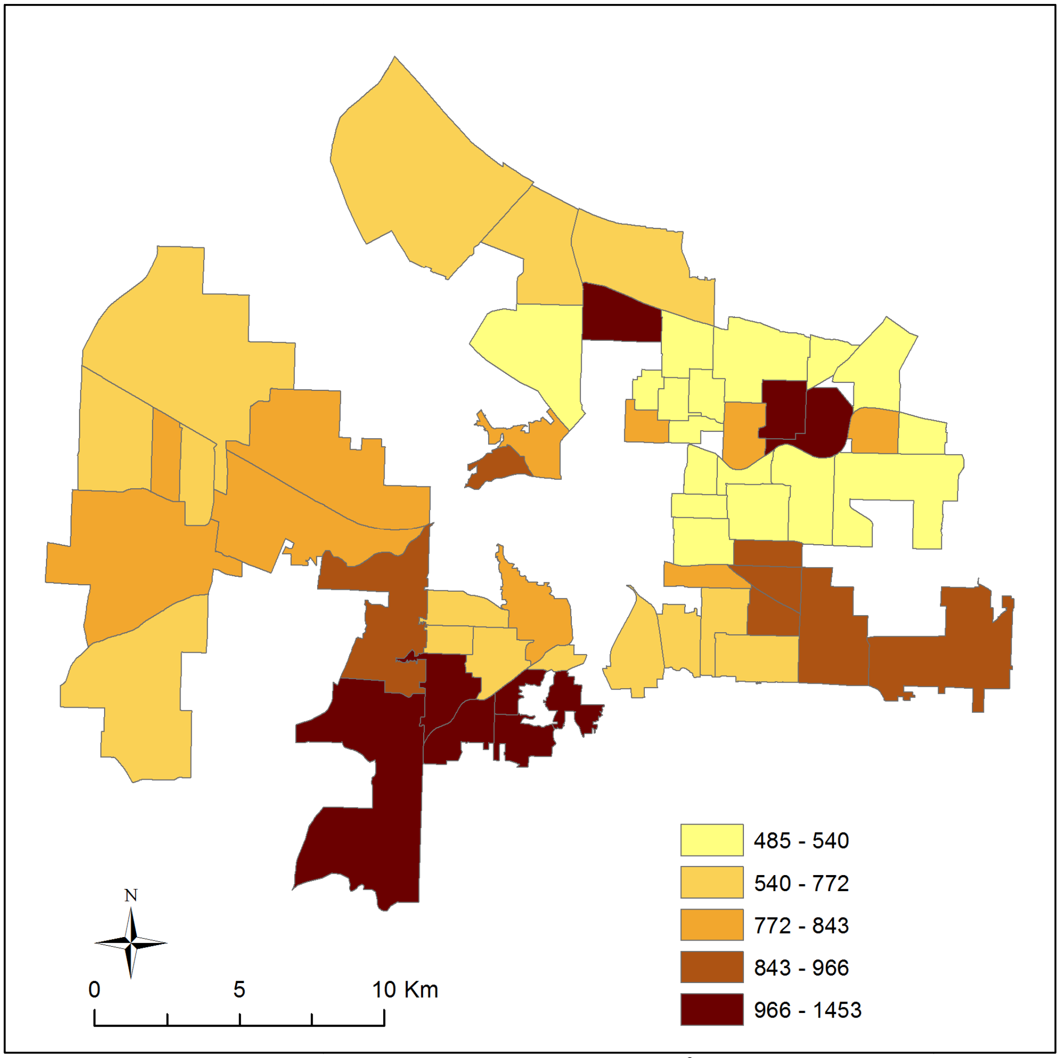

Figure 3. Property size at the RLIS neighborhood level (Unit: m^2)

Our mixed effects linear regression model indicated how much the statistical model could investigate contextual effect by neighborhoods. Hence, we created residual map in order to provide more detailed and visualized information on the map (Figure 4). Neighborhoods and households with high water consumption tended to have higher residual values. This may be related to high variability of these high water users and neighborhoods in terms of parcel level characteristics and other socio-demographic factors that affect summer water use. For instance, politically conservative households with high water consumption had various opinions on community participatory program for water conservation and planting in their garden. We discuss these issues in the following paragraphs.

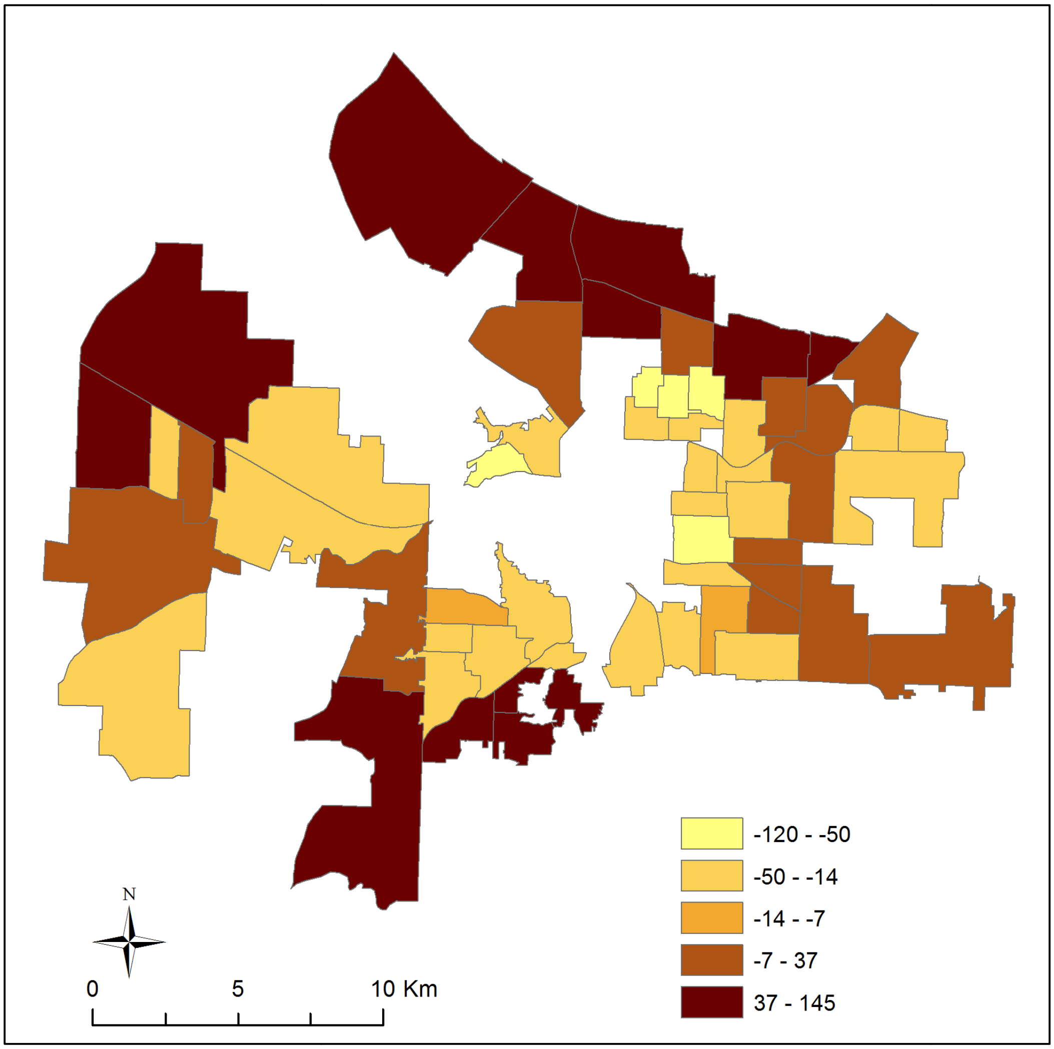

Figure 4. Residual Distribution of RLIS Neighborhoods (Unit: Gallons/day)

5.3 Relationship between Behavior and Water Consumption

Interesting patterns were found in the relationship between political tendencies and water conservation at the neighborhood level (Figure 5a). We found that the most politically conservative neighborhood (CPO7 Sommerset West Elmonica NS), which is located in far northwest side of the study area, has the highest summer outdoor water use (574.82 gallons per day (2175.93 liters)). Interestingly, the Beaumont-Whilshire neighborhood, which has the lowest water consumption and is located in northeastern part of the inner city, tended to be the most liberal neighborhood in this research (163.95 gallons per day (620.62 liters)) (Figure 5). Consequently, water administrators might consider spatial dimensions of political indicators and dispositions for planning water conservation policy in the future.

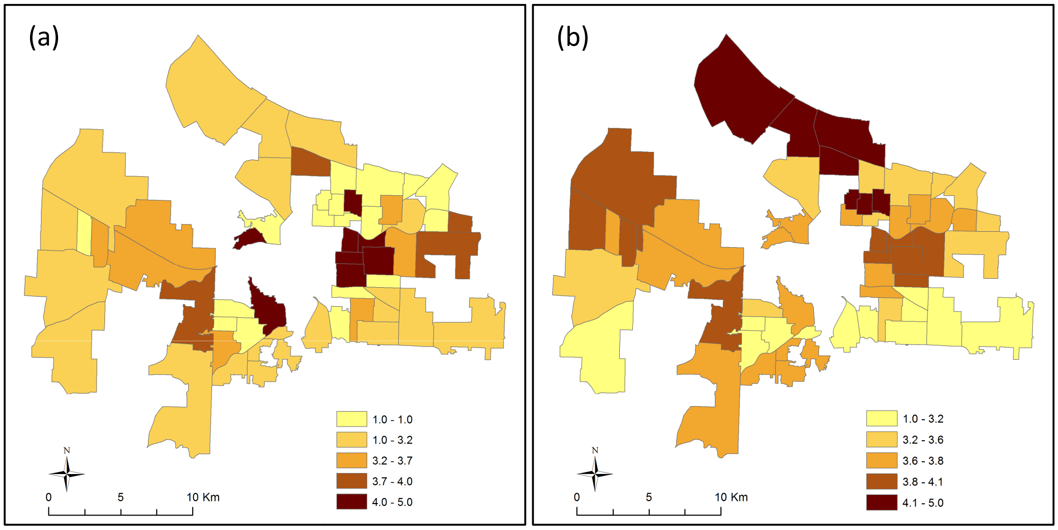

Figure 5. (a) Political Inclination (1: Very Conservative, 5=Very Liberal) and (b) community responsibility (1=Disagree, 5=Very Agree) by the RLIS Neighborhood level

Furthermore, we recognized the behavioral patterns in water consumption during the summer in Portland. One objective of the survey was to define the possible relation between water consumption level and the residents' attitudes about water resource conservation and community activities at the neighborhood level (Figure 5b). The more native planting households have in their yards, the less water use during summer (Figure 6a). In contrast, households with higher water consumption prefer to landscaping and gardening needing irrigation. For example, CPO 7 has the lowest score in native planting (0.11 out of 10), while Beaumont Wilshire the highest value (2.7 out of 10). Typically, suburban neighborhoods in the west side tend to use more water than inner city neighborhoods in the east side of Portland (Figure 2).

Households that have very active interest in water conservation programs and understand about water shortages during the summer attempted to reduce their water use. The Beaumont-Wilshire neighborhood (the lowest average summer daily outdoor water use), for example, showed the highest interest (4.37 out of 5) in participation in water conservation program. The use of native plants in their garden in the Beaumont-Wilshire neighborhood also lowered water consumption. In other words, households in the Beaumont Wilshire think that community activities can save the water and people in the neighborhood hold responsibility for water conservation. In contrast, the Pleasant Valley neighborhood had the lowest value in the community responsibility section (Figure 5b). The households in Pleasant Valley recorded the highest preference in lawn maintenance (Also, the larger size of lawn is better and lawn size is important in their outdoor space use, figure 6c and figure 6d).

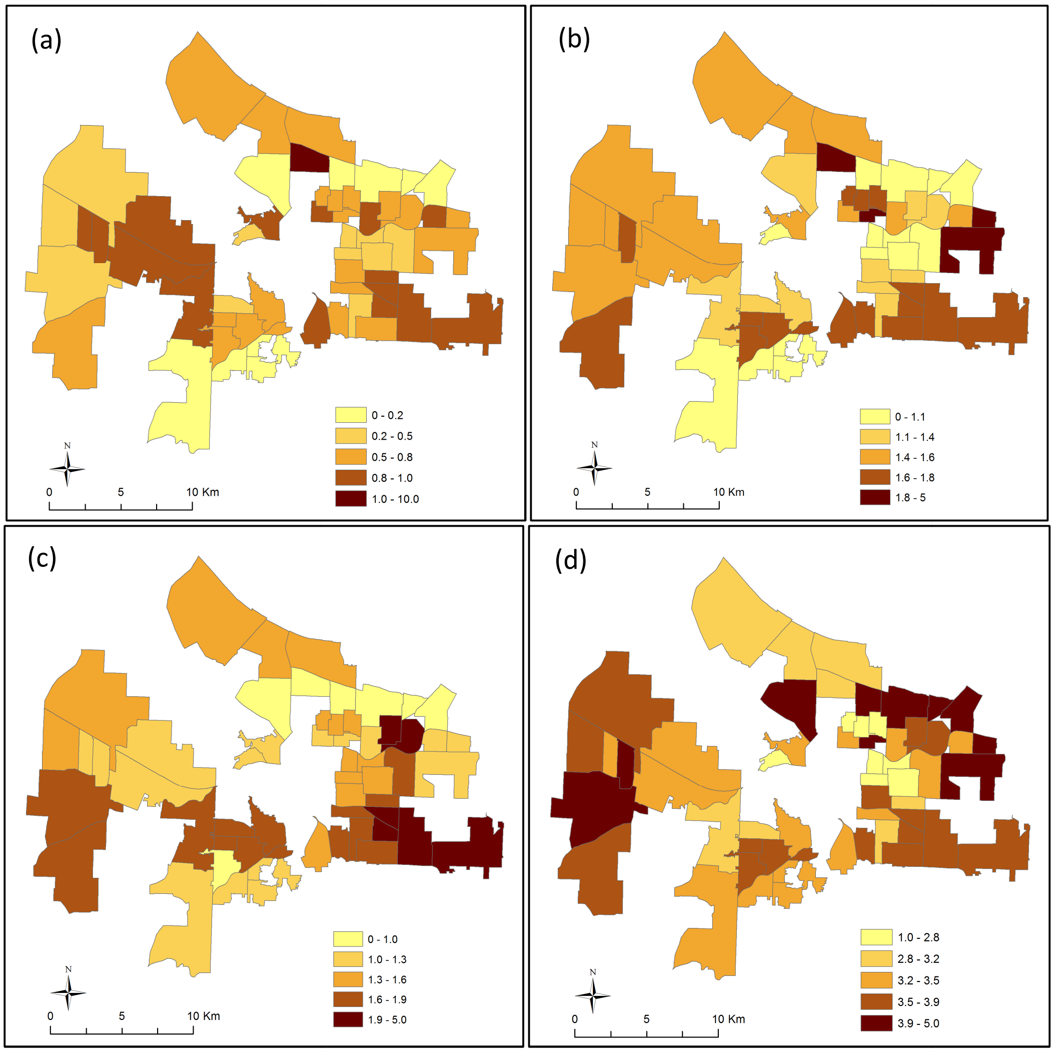

Figure 6. Survey responses (a) Native planting at the RLIS neighborhood level (0=0%, 10=100% in Backyard Use) (b) Neighbors' opinion is important in backyard use and watering (0=Disagree, 5=Very Agree) (c) Lawn size preference at the RLIS neighborhood level (Larger size of lawn is better; 0=Disagree, 5=Very Agree), (d) Lawn maintenance preference at the RLIS neighborhood level (Well-maintained and well-manicured lawn is better; 1=Disagree, 5=Very Agree)

When asked how important neighbors' opinion in water use (figure 6b), Sunnyside neighborhood had the lowest value (0.86), while the Woodlawn had the highest value (2.67 out of 5). Neighborhoods that cared about neighbors' water use (e.g., Woodlawn) tended to use more water in summer than other neighborhoods that don't care about their neighbors' behavior (Figure 2). This suggests that there may be peer pressure on water use at the neighborhood scale. Our analysis suggests a possible future direction of potential local water policy and community water saving programs at the neighborhood level.

5.4 MAUP AND THE RELEVANT SPATIAL SCALE

The analysis of spatial dependence indicated that characteristics of surrounding neighborhoods are potentially vital parameters in understanding water use behavior and community program planning for water conservation in the neighborhoods. The linear mixed-effects model was designed after we understood the traits of the variables at different scales. However, the multiple linear regression models and the linear mixed-effects model showed different statistical results due to the level difference. When we considered characteristics of variables in a large spatial area, such as the RLIS neighborhood scale, the determinants of water use are different. There was no significant association between variables of education and physical features (except for lot size) and attitudes to water conservation and summer water consumption at the zip code scale. However, household variables grouped in the RLIS neighborhoods indicated significant relationships with summer outdoor water consumption. This suggests that neighborhood boundary might be a better spatial context than administrative boundary such as zip code for understanding the dynamics of urban water consumption patterns.

6. CONCLUSIONS

This study integrated both theoretical and empirical insights for recognizing and elucidating the relationship between households' water consumption patterns and socio-demographic and behavioral characteristics in the Portland metropolitan area. Similar to previous water consumption studies in the Portland area, our results revealed that domestic water consumption was associated with socio-demographic data, building size, and household behavior toward water conservation issues (Sauri, 2013). Also, households with large buildings and big lots had a higher level of water consumption than those with smaller residence (March and Sauri, 2010; Runfalo et al. 2014).

At the same time, our research offered new insights into relationships between variables of socio-demographic and summer outdoor water use through linear mixed-effects model analysis. In terms of socio-demographic patterns of water use at the household scale, our results are consistent with previous studies on the impact of parcel level characteristics on water usage. This research attempted to find new water use patterns related to political preference, community responsibility, and individual attitudes toward water conservation at the household and neighborhood levels. Also, we found that the households' preference for aesthetic decoration in gardens tends to influence water consumption during the summer in Portland. Consequently, environmental and aesthetic attitudes at the household level can be associated with water use at both the household and neighborhood levels. Follow-up research is required to clarify the complex relationships between individual values and water conservation programs led by community or neighborhood associations.

There might be some limitations in our study. First, in linear mixed-effects analysis, we did not consider some households that are located nearby with each other in the neighborhood boundary, but they are included in different RLIS neighborhoods. Also, MAUP issues such as zoning and transportation could be not addressed in this study due to limited information. In addition, this research could not examine the interdependence between those households in the borderline as Edwards et al. (2005) found social pressure in water use in an adjacent area. Second, we did not consider summer precipitation changes each year. Climate variability (Breyer et al., 2012) can be another variable influencing water use, but our research design did not convey climatic traits in the process. Third, we did not address water price (Arbues et al., 2004), which can influence individual water consumption pattern during summer. Arbues et al. (2004) found the impact of water price changes onto water demand decreasing in residential households, but in our research water price is relatively homogeneous in our study area (Breyer and Chang 2014) given that our samples were drawn from only two adjacent water providers.

This research shows the importance of conducting a water consumption analysis at multiple levels - namely the household and neighborhood scales. We conclude that attitudes towards environmental issues and community activities as well as individual characteristics play important roles in explaining the variations in summer water consumption. Further research is needed regarding the effect of spatial dependence and water policy on community or neighborhood water consumption patterns. In this respect, the next research will focus on which water conservation policies for neighborhood participation or community programs at the neighborhood level influence water consumption patterns in households.

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