Trend analysis of domestic water consumption depending upon social, cultural, economic parameters


*Department of Civil and Environmental Engineering, Pusan National University, Busan, 609-735, Korea (E-mail: kimsangh@pusan.ac.kr; younglover15@pusan.ac.kr)
**Department of Environmental Engineering, University of Seoul, Seoul, 140-714, Korea (E-mail: jykoo@uos.ac.kr)
***Department of Environmental Engineering, Korea University, Korea (E-mail: eechoi@korea.ac.kr)
****Department of Civil and Environmental Engineering, Dankook University, Seoul, 140-714, Korea (E-mail: ihhyun@dankook.ac.kr)

Abstract Designs of water distribution systems and water resources planning and management can be obtained from a comprehensive investigation and analysis of water consumption data in real life systems. Water consumption patterns for domestic purposes were monitored at 145 households over a three-year period. Electric flow meters were installed at the ends of all of the household water taps. Water consumption patterns were analyzed to configure the water demand trends for social and cultural factors. Economic factors such as monthly income and the area of the floor plan were investigated to determine the impact of resident wealth on the patterns of water consumption. Water use data collected by a public water resources management firm in Korea, Kwater, had been filtered using both physical and probabilistic criteria to improve the credibility of the analysis. Both the Mann-Kendall and Spearman’s Rho tests were used to perform the trend analysis. Distinct factors in the patterns of water consumption can be determined to cause both increasing and decreasing trends in water use. Analysis of this data provides the basis of parameter configuration for a reasonable design of a domestic water-demand prediction model.

Keywords Characterization of water demand; trend analysis; water consumption

Introduction

A water distribution system is a public infra structure to support a domestic lifestyle as well as various conventional urban activities. The accurate prediction of water demand for cultural, social, residential, and economical factors is a critical issue for the reliable operation, planning, and management of an urban water supply system. Rankin and Rousseau (2006) had analyzed the sanitary hot water consumption pattern for the reliable design of heating systems in commercial and industrial sectors in South Africa. Climate induced reductions in water availability can be a primary issue for sustainable urban water supplies (Jenerette and Larsen, 2006). Prediction of urban water demand can be made with a time series model formulated with following parameters; trends in water use, seasonality, climate correlation, and autocorrelation (Zhou et al., 2000).

Water demand should be estimated based upon water use measurements in a field system. In conjunction with water use conditions, intensive monitoring programs of water consumption need to be performed to provide robust databases for the water consumption prediction model. Noise should be properly filtered from contaminated data. In this study, water consumption data had been collected to understand the water demand patterns for various domestic purposes and water usage conditions.

A proper methodology needs to be used to understand the collected data statistically and stochastically. Non-parametric statistical methods for trend configuration, the...
Mann-Kendall test, and the Spearman’s Rho test, were used to detect trends and variability in the hydrological regime of the Mackenzie river basin (Aziz et al., 2006), to detect monotonic trends in hydrological series (Yue et al., 2002), to detect trends in annual the maximum water level and streamflow of the Yangtze river basin (Zhang et al., 2006), and to evaluate monthly stream flow in Turkey (Kahya et al., 2004).

In this study, the Mann-Kendall and Spearman’s Rho tests were used to analyze trends in the water consumption data. The stochastic characteristics of water consumption can be evaluated with the specified statistical significance. Depending upon the values associated with economical, social, and cultural parameters for the corresponding water demand nodes, water consumption pattern can be characterized as decreasing, increasing, and unchanging. The impact of social, cultural, and economic parameters on the water consumption can be evaluated.

Data acquisition and filtering scheme

Data acquisition system

Water consumption data for this research was obtained from an intensive monitoring program developed for 145 houses evenly distributed throughout the Republic of Korea, by Kwater, a public water resources management firm in Korea, between Dec. 2002 and Feb. 2006. The electrical current meter, utilizing the fluid oscillator principle, was used to detect water consumption. Wireless data acquisition systems had been installed in 145 houses as shown in Figure 1. Multiple electronic current meters were installed in each house depending upon water usage purposes. Figure 2 shows the number of current meters installed and operated during the study period. Flow data from the electrical service water meter is transferred to a radio frequency module and the mobile control unit uploads the data to the server of the designated website. Samples were taken hourly and daily. Water consumption data was measured and collected for various water uses i.e. dish washing, watering plants, drinking, laundering, showering, and house cleaning as shown in Figure 2.

Filtering of data and water consumption characterization

The data suffered occasionally from errors associated with equipment failures, operation errors in the communication units, and unexpected noise. In order to ensure reliability, the recorded data needed be properly filtered. Single missing data points in the times series were replaced by an interpolation between the corresponding past and future data. Daily water consumption was used for analysis and confirm through comparison with the data collected during the previous 24 hour interval. Detecting and removing outliers are a critical preprocess of data management. In order to detect an outlier, a set point was needed. A physically meaningful limit for maximum water use can be determined by considering and testing the maximum water consumption for each purpose such as,

Figure 1 Wireless data acquisition system of water consumption data; AMR: Automatic Meter Reading, CDMA: Code Division Multiple access, MCU: Mobile Control Unit

Figure 2 Water consumption data monitoring and collection system; AMR: Automatic Meter Reading, CDMA: Code Division Multiple access, MCU: Mobile Control Unit
showering, laundering, dish washing, bathing, and plant watering (Kwater, 2006). The maximum amount of each water-using machine per day and the water capacity of these machines were investigated through an independent questionnaire distributed to 158 houses and the manuals of the primary water-using machines. The average number of people in each family occupying the 158 abodes was 3.5. More than 90% of the households responded positively for bathing, laundry and cooking for water usage, while 75.3% reported house cleaning and plant maintenance. Answers from questionnaires for each purposes, laundry, bath, duration and frequency of showering, sinking basin, number of toilet usage per day, watering time for miscellaneous purposes were collected and analyze in the decision making procedure. The physical characteristic of water storage, i.e. maximum capacity of bathtubs, showers, and toilets were also considered. The maximum allowable water consumption can vary by the number of family members in the residence. The mean of corresponding water usage can also be evaluated from the recorded data.

Due to the significant differences between mean and maximum limit of water usage for a family, determining of the maximum allowable water consumption limit should be taken into consideration the number of people in the residence. The non-exceedance probability has used to determine the proper levels for water usage considering the number of toilet use per day, showering time, amount of laundry, garden watering time, cleaning time for balcony and gallery. The Weibull formula was used to compute the non-exceedance probability of number and duration of use of water machinery (Chow et al., 1988). Maximum allowable amount of water consumption can be determined from the analysis with non exceedance probabilities of 50, 80, 90, 95, and 99% and average number of people in residence. The limit of maximum amount of water use per person and maximum amount of allowable water consumption compared and the data over either of set points were removed for further consideration.

Investigation of social, cultural and economic parameters

In order to understand the characteristics of water usage and the effective parameters for water consumption patterns on context in the social, cultural and economical factors of homes were investigated using other questionnaires as shown in Table 1 to monitor flow in households as shown in Figure 1.

Table 1 indicates the items in the questionnaire distributed to households to record flow data. Social and cultural factors can be merged into customized factors as shown in Table 1. Water consumption patterns can be associated with the house types i.e. apartments, terraced houses, multiplex houses, and independent houses. The economic factors impacting water consumption patterns include the average income of the residence and

![Figure 2](https://iwaponline.com/ws/article-pdf/7/5-6/61/477397/61.pdf)
the area of the floor plan. Analysis of the items shown in Table 1 of the 136 responses of the 145 questionnaires provides comprehensive insight into the impact of the various parameters on the potential variations in domestic water consumption.

Statistical methods for trend analysis. The trend analysis based upon the null hypothesis, Ho that there is no trend in the data. The Mann-Kendall test has been commonly used as a non-parametric statistical trend analysis method due to its greater suitability for evaluating non-normally distributed data or censored data (Mann, 1945; Kendall, 1975).

\[ S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}(x_j - x_i) \]  

(1)

where the \( x_i \), \( x_j \), are data series and \( n \) is the number of data items.

\[ \text{sgn}(\phi) = 1, \text{ if } \phi > 0; \quad 0, \text{ if } \phi = 0; \]  

(2)

If the null hypothesis, \( H_0 \), is true, then \( S \) is approximately normally distributed with \( \mu = 0 \) and \( \sigma = n(n-1)(2n+5)/18 \). The Z-statistic is expressed as

\[ Z = \begin{cases} 
(S - 1)/\sqrt{\sigma(S)} & \text{if } S > 0 \\
0 & \text{if } S = 0 \\
(S + 1)/\sqrt{\sigma(S)} & \text{if } S < 0
\end{cases} \]  

(3)

The significance levels can be obtained from the normal probability tables. A positive value of \( S \) indicates that there is an increasing trend and vice versa.

Spearman’s Rho test is another non-parametric rank order test. The null hypothesis Ho of Spearman’s Rho test against trend tests is that all data are independent and identically distributed. The alternative hypothesis is that the series increases or decreases. The test statistic, \( \rho_s \), is the correlation coefficient, which is obtained in the same way as the usual sample correlation coefficient, but using ranks as,

\[ \rho_s = 1 - \frac{6\sum_{i=1}^{n} [R(x_i) - i]^2}{n(n^2 - 1)} \]  

(4)

where \( R(x_i) \) is the rank of ith observation and \( x_i \), in the sample size \( n \). Under the null hypothesis, the distribution, \( \rho_s \), is asymptotically normal with a mean of 0 and a variance of \( 1/(n-1) \). The significance levels can be obtained from the normal probability table.

Table 1 Social, cultural and economical factors of the questionnaire for trend analysis

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water consumption characteristics</td>
<td>Number of generations in the family, Existence of infant, Existence/number of teenager, Number of rooms, toilets, and bathrooms, Existence of toilet washing machine (bidet), Primary drinking water source, Existence of a domestic drinking water treatment system, Number of laundries per day, Average meal number per day, Occupation of resident, Education of resident, Evaluation of water bill relative to other living expenses, Residential type, House type</td>
</tr>
<tr>
<td>Customized factors (social and cultura parameters)</td>
<td>Average income per month, Number of meals eaten out, Area of house, The number of tax paying individuals</td>
</tr>
<tr>
<td>Economic factors</td>
<td>Average income per month, Number of meals eaten out, Area of house, The number of tax paying individuals</td>
</tr>
</tbody>
</table>
For large samples, the quantity, \( rS\sqrt{n} - 1 \), should be approximately normally distributed with a mean of 0 and a variance of 1.

**Analysis and discussion**

Analysis of the Mann-Kendall and Spearman’s Rho tests would indicate that the trend exists if the evaluated statistics are greater than 2.58 for a confidence level of 99%. The sign of the \( S \) statistics of the Man-Kendall test identifies an increasing or decreasing trend. Table 2 presents the examples of the statistical trend analysis of several uses of water for two residents, S13 and S32, located in Seoul. The statistics for the trend analysis can be computed for several water consumption purposes such as housework, laundry, toilet use and bathing. Seoul 13 (S13) is a multiplex residential house, and the \( Z \) and \( rS\sqrt{n} - 1 \) statistics for cold water in washbasin 1 are 5.74 and 5.63, respectively. The \( S \) statistic for cold water in washbasin 1 is 45,550 indicating an increasing trend. \( S \), \( Z \), and \( rS\sqrt{n} - 1 \) for the toilet at S13 are -66,240, 8.35, and 9.42, respectively, which indicate a decreasing trend for water use in toilet. Similar ranges of \( Z \) and \( rS\sqrt{n} - 1 \) can be found for all water consumption purposes except usage in the kitchen sink.

The residential type of Seoul 32 (S32) is an apartment. As presented in Table 2, the water use trends in S32 between washbasins 1 and 2 are different. Hot water for washbasin 1 had an increasing trend and cold water from washbasin 2 flow, an increasing trend. This suggests that washbasins 1 and 2 could be used for different purposes such as one for face and hands and other for floor cleaning the floor. Even though the statistics for the toilet and bathtub for Seoul 32 had decreasing trends, the daily sum for this apartment had an increasing trend because that average water usages for the toilet and bathtub are 13 and 7401 per day, respectively, but the kitchen sink and washbasins are 4,390 and 4,5201 per day, respectively.

As shown in Table 2, statistics for the use of water suggest by the particular pattern for the corresponding house. However, the comprehensive comparative analysis for each use may not be reasonable due to the difference of water distribution and resident composition between each household. Therefore, trend analysis for daily sum was performed for all households where flow was monitored.

Considering the responses from the questionnaire in Table 1, the frequency analysis evaluated the impact of each parameter on water consumption. Figure 3 shows the distinct frequency distributions as percentage from the trend analysis for several social, cultural and economic parameters. Apparent increasing trend for the existence of infants as a family member and double income families apparently have increasing trends, while the opposite conditions resulted in decreasing trends as seen in Figures 3(a) and (b). The existence of infants and double incomes can be significant social and cultural factors in the increase of water consumption. Infants may account for additional water use due to frequent washing and laundering. Double income families often have maids or babysitters, perhaps such employees are less concerned with the water bill and thus increase usage. Figure 3(c) shows the frequency distribution of water consumption trends for owned and leased residential types. Similar frequencies can be found between increasing and decreasing trends for the owned residences. The frequency distributions of the leased residences are substantially different from the owned. The frequency of the increasing trends is 2.5 times that of the decreasing trends. This difference may be caused by the property leases once stipulating the water bill was paid by the owner of the house. In households purchasing drinking water apparent decreasing trends can be observed as seen in Figure 3(d). Monthly income seems to be an important factor for determining trends (Figure 3(e)). Greater income may allow family members to use more water. Figure 3(f) presents the trends in the distribution for family composition single or multiple generations. The number of generations in a
Table 2. Statistics for Mann-Kendall test and Spearman’s Rho test for two residential places, S13 and S32 in Seoul; The numbers in boldface compare with normality table.

<table>
<thead>
<tr>
<th></th>
<th>Statistics</th>
<th>Washbasin 1</th>
<th>Washbasin 2</th>
<th>Washer</th>
<th>Toilet</th>
<th>Bathtub</th>
<th>Kitchen sink</th>
<th>Daily Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>HOT WAT.</td>
<td>COLD WAT.</td>
<td>HOT WAT.</td>
<td>COLD WAT.</td>
<td>HOT WAT.</td>
<td>COLD WAT.</td>
<td></td>
</tr>
<tr>
<td>S 13</td>
<td>S</td>
<td>19,970</td>
<td>45,550</td>
<td>193,500</td>
<td>−39,810</td>
<td>−66,240</td>
<td>24,800</td>
<td>−17,77</td>
</tr>
<tr>
<td>M</td>
<td>Z</td>
<td>2.28</td>
<td>5.74</td>
<td>24.39</td>
<td>5.02</td>
<td>8.35</td>
<td>3.13</td>
<td>0.22</td>
</tr>
<tr>
<td>S</td>
<td>$p_S \sqrt{n-1}$</td>
<td>2.28</td>
<td>5.62</td>
<td>22.46</td>
<td>3.43</td>
<td>9.42</td>
<td>3.25</td>
<td>0.07</td>
</tr>
<tr>
<td>S 32</td>
<td>S</td>
<td>115,800</td>
<td>−13,240</td>
<td>−11,830</td>
<td>21,800</td>
<td>−26,590</td>
<td>48,470</td>
<td>−31,200</td>
</tr>
<tr>
<td>M</td>
<td>Z</td>
<td>14.00</td>
<td>1.60</td>
<td>1.49</td>
<td>4.09</td>
<td>1.43</td>
<td>2.64</td>
<td>3.22</td>
</tr>
<tr>
<td>S</td>
<td>$p_S \sqrt{n-1}$</td>
<td>13.74</td>
<td>1.71</td>
<td>1.86</td>
<td>6.31</td>
<td>1.94</td>
<td>3.08</td>
<td>3.16</td>
</tr>
</tbody>
</table>

S.H. Kim et al.
Figure 3 Frequency diagrams as percentage for trend analysis; The existence of infant, (a); The existence of double income family, (b); Residential type (c); Type of primary drinking water (d); Monthly income as US dollars (e); Number of generations (f); I.T: Increasing Trend, D.T: Decreasing Trend, E: Existence, NE: Non Existence, Priv.: Owner, Lsd.: Leaser, D.W.: Domestic Water (tapwater) as Drinking Water, Etc.: Drinking Water from Other Sources

Table 3 Distinct influential factors for the determination trend for the domestic water consumption

<table>
<thead>
<tr>
<th>Classification</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing</td>
<td>Existence of infant, Greater number of laundry, Greater number of generations in the family, Residential type as lease</td>
</tr>
<tr>
<td>Customized factors</td>
<td>Greater area of house, Greater monthly income, Greater number of meals eaten out, Double income family</td>
</tr>
<tr>
<td>Economical factors</td>
<td>Non-existence of infant, Purchased water as drinking water, Less number of laundry, Less number of generations in the family, Lower education resident, Residential type as owner</td>
</tr>
<tr>
<td>Decreasing</td>
<td>Less area of house, Less monthly income, Low frequency of meals eaten out, Single income family</td>
</tr>
</tbody>
</table>
residence is an important cultural factor. The amount of water consumed increased substantially as the number of generations increased. Also, the residences with the greatest number of generations had the fewest decreasing trends. Water purifiers and the number of rooms had a negligible impact on the variation of water consumption.

Table 3 describes the factors affecting the trend existence of water consumption. Other social and cultural factors, such as, the presence of domestic water purification systems, teenagers as family members, the number of rooms, household types, the number of toilets or bathrooms, occupation of residents, evaluation of water bill to other living expenses had no impact on trends in water consumption. However, most economic factors had significant effect on the water consumption patterns of the residents.

Conclusion
Domestic water consumption data had been collected for 145 houses using electric meters and wireless data acquisition systems for three years. The monitoring program considered water usage conditions such as consumption characteristics and the distributions of the purpose of water usage for each study location. Considering the physical and statistical characteristics of water consumption, an appropriate filtering scheme was used to record a time series to improve the reliability of the trend analysis. The Mann-Kendall test and Spearman’s Rho test identified several distinct social, cultural, and economic factors that influenced the water consumption trends. Factors affecting increase in domestic water consumption were infants as family members, the number of laundry, whether tap water was used for drinking water, and the number of family generations living at the residence. The economic factors causing increased water consumption are a larger number of meals eaten out, a larger area of residence and higher income and a double income. Factors causing a decrease in water consumption were the absence of an infant as a family member, using bottled water as drinking water, a low educational level, a smaller residence area, and fewer meals eaten out. This analysis deduces a cluster of parameters to improve the prediction of domestic water demand. Further analysis of several of the uses of water that have distinct influences could be a useful research issue for efficiently managing and planning urban water facilities.

Acknowledgements
Authors would like to thank the financial support in the form of grant from Kwater.

References