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Influence of a season on hourly and daily variations in water demand patterns in a rural water supply line – case study

Tomasz BERGEL[1) ADEF] ✉, Bartosz SZELĄG[2) ACDF], Olga WOYCIECHOWSKA[1) ABDEF]

[1)] University of Agriculture in Kraków, Department of Sanitary Engineering and Water Management, al. Mickiewicza 21, 31-120 Kraków, Poland; e-mail: t.bergel@ur.krakow.pl, o.woyciechowska@gmail.com
[2)] Kielce University of Technology, Department of Geoengineering, Geomatics and Waste Management; e-mail: bartoszszelag@op.pl

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Abstract

This article presents the results of a study on hourly and daily variations in water demand patterns, depending on a season. The study was conducted in the years 2014–2015 on a selected rural water supply line. The analysis was based on values of hourly water demand as measured by a water meter coupled with a recording device. The research showed that both the volume and fluctuations in daily water demand were higher in the spring and the summer, versus the autumn and the winter. This was most probably caused by water consumption for additional purposes, specific for rural areas. Individual water demand was the highest in the summer, and the lowest in the winter. Two peaks for hourly water demand were determined for the analyzed seasons. The morning peak always occurred at 7 a.m. on working days, while on days off work it fell at 9 a.m. or 10 a.m., depending on the season. The evening peak always fell at 8 p.m., regardless of a season or a day of a week. On working days, the evening peak was always higher than the morning one, while on days off work the morning peak was higher than the evening one in the autumn and in the winter, and both peaks were the same in the spring and in the summer.

Key words: *amount and irregularities demand, municipal water supply system, water demand, water demand peaks*

INTRODUCTION

The natural environment is subject to continuous changes. They are reflected in climate [BINIAK-PIERÓG *et al.* 2012; NIERÓBCA *et al.* 2013], passing seasons, in courses of rivers and streams, or in fluctuations in groundwater table levels. As humans are an integral part of the nature, their lives also undergo continuous changes. These variations, both short- and long-term are visible for all aspects [PIASECKI *et al.* 2016]. For example, it is visible for consumption of water supplied by municipal systems [GARGANO *et al.* 2016]. The water demand is subject to seasonal, weekly, daily, or even hourly variations. These variations are influenced by various conditions alike, including the climate [CABRAL *et al.* 2016; CHANG *et al.* 2014; KOLEDO 2016], and a local situation, for example, water supply and sewage facilities in flats [AGUDELO-VERA *et al.* 2014; BALTAS, MIMIKOU 2005; BERGEL, KACZOR 2007; PAWEŁEK, KACZOR

2006]. Additionally, a type of a place (tourist, rural, urban, suburban) together with habits and lifestyle of its inhabitants play an important role, shaping the water demand patterns. Some authors also suggested other factors, including price of water and a fee for discharging wastewater [KOLEDO 2016] or tightness of water supply lines [IWANEK *et al*. 2015].

Variations in the water demand are also influenced by a season of a year. GRUSZECKI and KANAREK [2004], in their study conducted at a tourist place (Kołobrzeg), found an increase in water consumption in the summer, maintained for several dozen days. Contrary to that, the lowest demand for water occurred in the winter (excluding a winter holiday period, associated with an increase in tourism). Similar conclusions were drawn by PAWEŁEK and KACZOR [2006], who studied the water demand in a detached house in Krakow, where average water consumption was significantly higher in the summer versus other seasons. BERGEL and KACZOR [2007], in their study covering two farms in Małopolska province, also found that the demand was the highest from May to July, and the lowest from January to March. Another analysis of water demand patterns in 35 buildings in Mszana Dolna, conducted by CHMIELOWSKI *et al*. [2009], revealed that its maximum values were noticed in detached houses in the summer and in multi-family houses in the spring and the summer. The lowest demand was observed in detached houses in the autumn and in multi-family houses in the winter.

Seasonal fluctuations in the water demand are also associated with additional needs, more frequently occurring in detached versus multi-family houses, and including washing of cars and agricultural equiCIent, maintaining cleanness in building surroundings and on pavements, watering of gardens, green areas or flower beds, breeding of farm animals, diluting plant protection agents, and other purposes, for example, construction works [BERGEL, PAWEŁEK 2005].

The aim of this study was to evaluate an effect of a season on hourly and daily variations in water demand patterns in a small water supply line.

STUDY SUBJECT AND METHODS

The study on the water demand patterns was conducted in a water supply system in a village Wola Zachariaszowska (Zielonki commune, Kraków district, Małopolska province). It covered two years (2014–2015) divided into calendar seasons. The analysed water supply system delivers water to households, service facilities, and public utility buildings (a school and a kindergarten). The number of households connected to the network was 355 in 2014 and 364 in 2015, and the number of inhabitants increased from 875 in 2014 to 905 in 2015.

Readouts from a water meter Sensus MelStream Plus 80 with a Sensus HRI-Mei B4 module sending impulses to a recording device connected with a comprehensive system monitoring operation of components of the water supply system in the whole commune were used in the analysis. The water meter was installed on an outlet duct from an initial reservoir in the network, and the recording device recorded the readouts at full hours.

Prior to the analysis, the values of the hourly water demand were standardized by dividing the flow volume at a time *t* by the total daily water demand for individual days. Then atypical water demand distribution patterns, including random events such as failures or the tank cleaning, were eliminated using the Grubbs' test [STANISZ 2007].

Coefficients of irregularity in the daily and the hourly water demand patterns in each season were determined for the studied facility. The daily coefficient of irregularity was calculated as a ratio of the maximum daily demand to the average daily demand in the analysed period. The hourly coefficient of irregularity was determined for days with the maximum water demand as a ratio of the maximum to the average hourly water demand.

Statistical analyses were conducted for the obtained time series, starting with an analysis of the variation in the water demand at individual hours during a day, on a basis of box and whiskers diagrams. Then, using the *k*-means method, the hourly water demand distribution patterns were determined for working days and for days off work (holidays, Saturdays, Sundays) in individual seasons. In this method, the *k* number of clusters was selected, maximally different from each other. The calculations required selecting in advance a specific number of clusters into which the set would be divided. This way, a *k* number of subsets were created, and then the items were moved within, to ensure the largest possible distance between them within the subsets. In this procedure the actions described above were performed simultaneously, striving to achieve the most effective separation of the clusters. In the conducted analysis, the assumed number of iterations was 10, and the number of clusters, *k*, was 2. This corresponded to two clusters of variations in the daily water demand in individual seasons: working days and days off work.

RESULTS ANALYSIS AND DISCUSSION

The conducted analysis showed that the water demand was the highest in the summer, and the lowest in winter, corresponding to 28% and 21.5% of the annual demand, respectively. The obtained results were consistent with studies of other authors [BERGEL, KACZOR 2007; CHMIELOWSKI *et al*. 2009; GRUSZECKI, KANAREK 2004; PAWEŁEK, KACZOR 2006].

Mean water demand per a statistical inhabitant ranged from 109.0 $dm^3 \cdot CI^{-1} \cdot d^{-1}$ in winter to 135.8 $dm^3 \cdot CI^{-1} \cdot d^{-1}$ in the summer. Observed irregularities in demand were the highest in the summer, with a maximum value of 332.6 $dm^3 \cdot CI^{-1} \cdot d^{-1}$ during a day, and the lowest in the autumn (191.0 $dm^3 \cdot CI^{-1} \cdot d^{-1}$). The lowest daily demand of 80.0 $dm^3 \cdot CI^{-1} \cdot d^{-1}$ was observed in the winter (Tab. 1).

Table 1. Water demand in individual seasons

Season	Water demand, $dm^3 \cdot CI^{-1} \cdot d^{-1}$		
	mean	min	max
Winter	109.0	80.0	203.3
Spring	117.2	83.4	320.0
Summer	135.8	90.3	332.6
Autumn	131.9	83.0	191.0

Source: own study.

Furthermore, it was found that in the winter 78% of observed values for the water demand were within the range of 90–120 $dm^3 \cdot CI^{-1} \cdot d^{-1}$. On the other hand, in the spring and in the summer, 79% and 65% of all observations, respectively, were characterized by the demand at a level of 100–150 $dm^3 \cdot CI^{-1} \cdot d^{-1}$. In the autumn, two peaks in the water demand occurred, resulting possibly from the varying water demand in the two analysed years. The first of those peaks (100–120 $dm^3 \cdot CI^{-1} \cdot d^{-1}$) represented 36% of analysed values, while the second (140–160 $dm^3 \cdot CI^{-1} \cdot d^{-1}$) accounted for 30% of the observations. The presented histograms show that the daily demand spanned a wider range in the spring and in the summer (80–340 $dm^3 \cdot CI^{-1} \cdot d^{-1}$) than in the winter or the autumn (70–220 $dm^3 \cdot CI^{-1} \cdot d^{-1}$) (Fig. 1). This situation could result from the water demand for other purposes, as discussed in another paper [BERGEL, BUGAJSKI 2008].

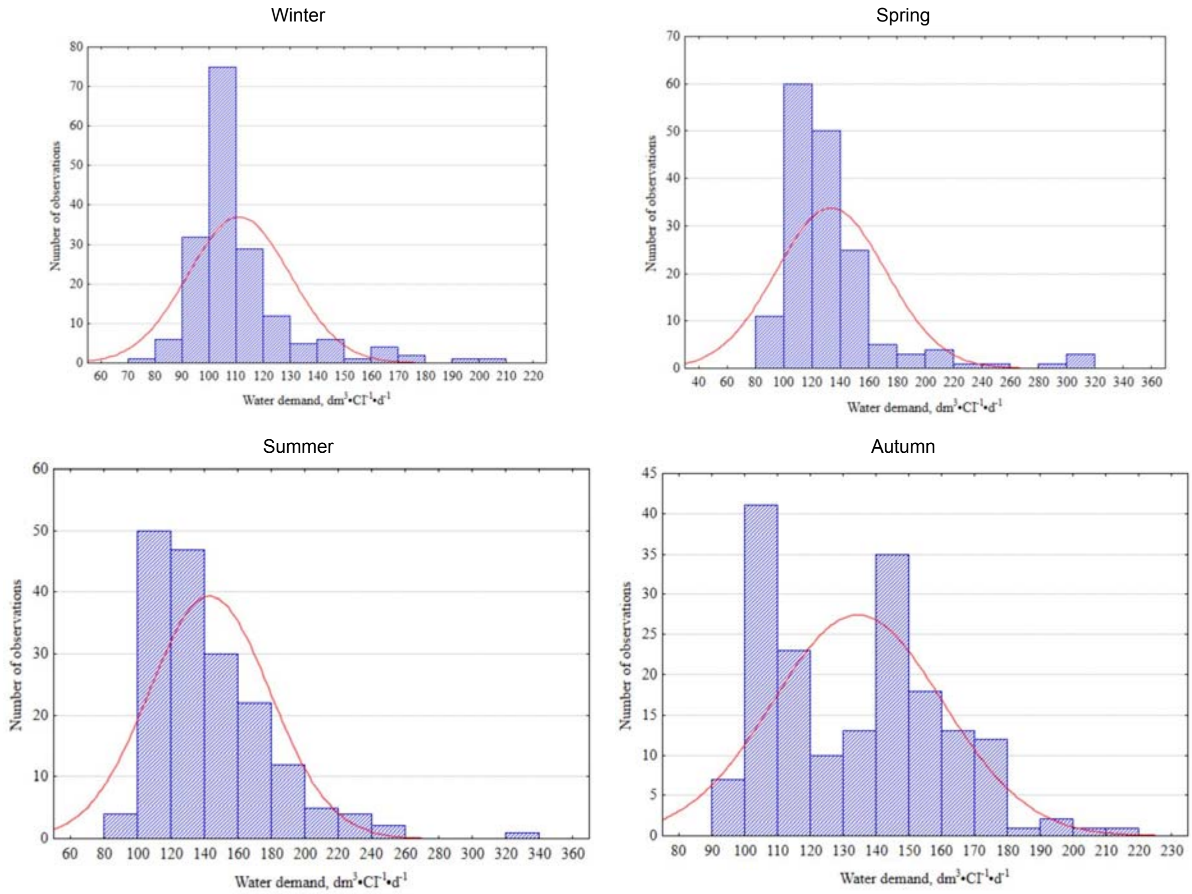

Fig. 1. Histograms for daily water demand in each season; source: own study

Table 2. Coefficients of irregularity for daily and hourly water demand in each season

Season	N_d	N_h
Winter	1.86	1.83
Spring	2.42	2.01
Summer	2.37	1.67
Autumn	1.60	2.40

Source: own study.

Additionally, the analysis of irregularities in the water intake during individual seasons was supplemented with calculating the coefficients of daily and hourly irregularities (Tab. 2). The demand pattern characterized by the N_d coefficient was significantly more varied in the spring and the summer, than in the autumn and the winter. Similarly as for the daily demand (Fig. 1), its higher variability in those periods could result from the demand for additional purposes.

The coefficient of hourly irregularity, N_h, ranged from 1.67 for the summer to 2.40 for the autumn.

Then box-whiskers diagrams were plotted for each season, describing a share of the hourly water demand in the total daily water demand. Figures 2 and 3 show, as an example, variations in the hourly water demand for working days and for days off work during the summer. Quartile interval values revealed that

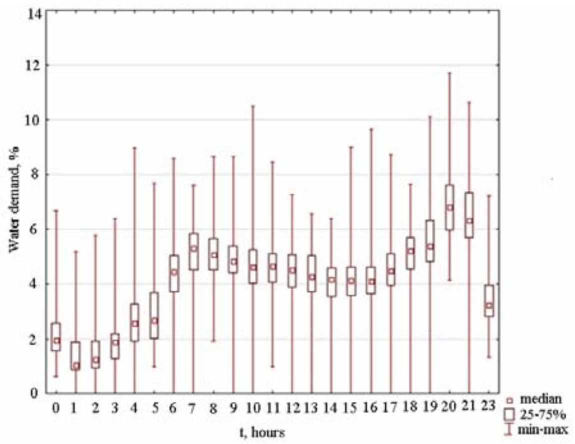

Fig. 2. A distribution of an hourly water demand on working days during a summer; source: own study

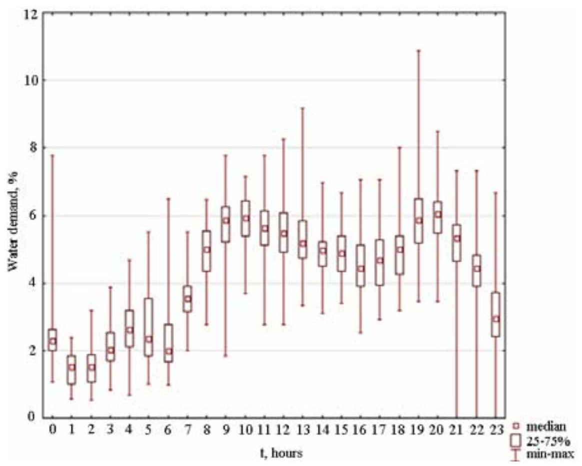

Fig. 3. A distribution of an hourly water demand on days off work during a summer; source: own study

the variation in the hourly water demand in the analysed settlement unit was more extensive on days off work than on working days. When analysing minimum and maximum percentage values of the hourly water demand it was also found that they varied significantly, both at individual hours of a day, as well as when working days were compared to days off work.

With the above calculation results considered (Figs. 2, 3), distribution patterns for the hourly water demand for working days and for days off work during the spring, the summer, the autumn and the winter were determined using the *k*-means method. The results are shown in Figures 4 and 5.

The conducted analyses showed that on days off work and on working days alike there was a morning and an evening peak in the water demand. On working days, the morning and the evening peak was at 7 a.m. and at 8 p.m., respectively, in all analysed seasons. For days off work, the morning peak occurred at 10 a.m. in the summer, the autumn and the winter, and at 9 a.m. in the spring. The evening peak on days off work fell at 8 p.m. in all seasons.

The obtained distribution patterns let us conclude that on working days the evening peak exceeded the morning peak in all analysed seasons. On the other hand, on days off work in the autumn and the winter, the morning peak exceeded the evening one, while in the summer and in the spring the morning peak was the same as the evening one.

Furthermore, the conducted analyses showed that value of the hourly water demand during the morning peak, both on working days and on days off work, was the lowest in the summer and the highest in the winter. Also during the evening peak, for both categories of days, the demand was the highest in the spring and the lowest in the autumn.

The calculations also showed that on the working days the lowest water demand between the morning and the evening peaks occurred at 2 p.m. (at 3 p.m. in the winter). For days off work, those minimum values were observed later, at 5 p.m. in the winter and the autumn, and at 4 p.m. in the summer and the spring.

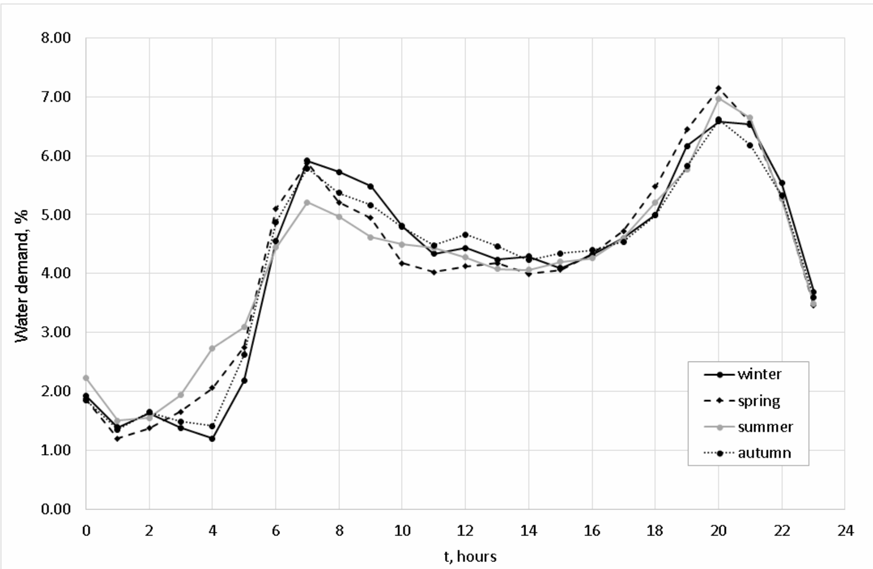

Fig. 4. Mean hourly water demand on working days during each season; source: own study

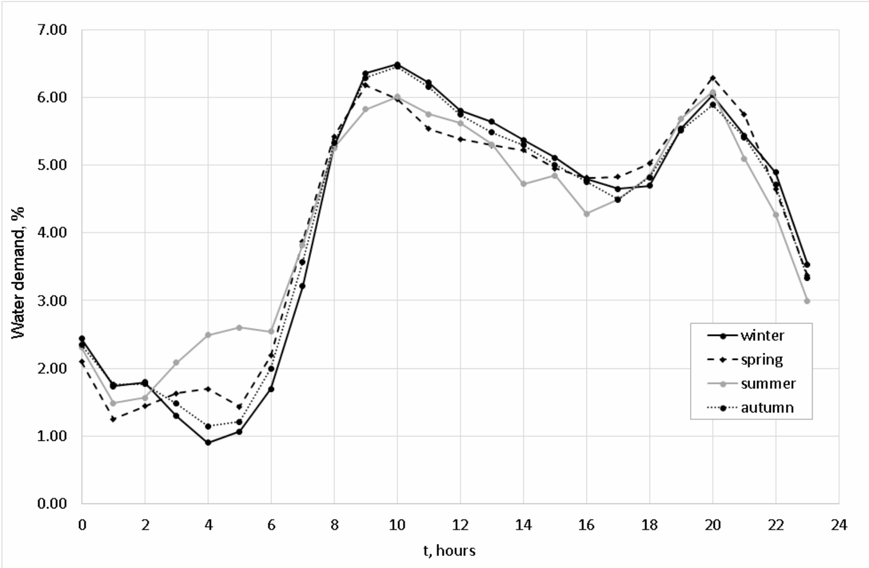

Fig. 5. Mean hourly water demand on days off work during each season; source: own study

The final important conclusion of the conducted analysis was that during days off work the distribution patterns of the hourly water demand were very similar in the autumn and in the winter.

CONCLUSIONS

1. The study conducted on the selected water supply system proved that the values of minimum, mean and maximum individual water demand were the highest in the summer and the lowest in the winter.

2. Both the volume and fluctuations in daily water demand were higher in the spring and the summer, versus the autumn and the winter. This was most probably caused by water consumption for additional purposes, specific for rural areas.

3. The established distribution of the hourly water demand was characterized by a significant variation, both at individual hours of a day, as well as when working days were compared to days off work.

4. On working days and on days off work alike there was a morning and an evening peak in the water demand.

5. The morning peak always occurred at 7 a.m. on working days, while on days off work it fell at 9 a.m. or 10 a.m., depending on the season.

6. The evening peak always fell at 8 p.m., regardless of a season or a day of a week.

7. On working days, the evening peak was always higher than the morning one, while on days off work the morning peak was higher than the evening one in the autumn and in the winter, and both peaks were the same in the spring and in the summer.

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Tomasz BERGEL, Bartosz SZELĄG, Olga WOYCIECHOWSKA

Ocena wpływu pory roku na zmienność dobowego i godzinowego zapotrzebowania na wodę w wodociągu wiejskim – studium przypadku

STRESZCZENIE

W artykule przedstawiono analizę wyników badań zmienności dobowego i godzinowego zapotrzebowania na wodę w wybranym wodociągu wiejskim. Wykonano ją dla dni tygodnia i pór roku w latach 2014–2015. Podstawą do przeprowadzenia analizy były wartości godzinowego zapotrzebowania na wodę zmierzone za pomocą wodomierza współpracującego z rejestratorem zamontowanego na przewodzie odpływowym z początkowego zbiornika sieciowego. Przeprowadzone badania wykazały, że wartość i nierównomierność dobowego zapotrzebowania na wodę była większa wiosną i latem niż jesienią i zimą. Najbardziej prawdopodobną przyczyną takiego stanu było występowanie celów dodatkowych zużycia wody, charakterystycznych dla terenów wiejskich. Jednostkowe zapotrzebowanie na wodę największe wartości przyjmowało latem, a najmniejsze zimą. W analizowanych porach roku stwierdzono występowanie dwóch szczytów godzinowego zapotrzebowania na wodę. W dni powszednie szczyt poranny przypadał zawsze na godzinę 7, natomiast w dni wolne od pracy, w zależności od pory roku, na godzinę 9 lub 10. Z kolei bez względu na porę roku i dzień tygodnia szczyt wieczorny przypadał zawsze na godzinę 20. W dni powszednie szczyt wieczorny był zawsze większy od szczytu porannego, natomiast w dni wolne od pracy zimą i jesienią szczyt poranny był większy od wieczornego, a latem i wiosną wartości szczytowe były takie same.

Słowa kluczowe: *szczyty poboru wody, wartość i nierównomierność zapotrzebowania, wodociągi wiejskie, zapotrzebowanie na wodę*