Journal of Ecological Engineering
Volume 17, Issue 3, July 2016, pages 47–52
DOI: 10.12911/22998993/63312

Research Article

DAILY WATER CONSUMPTION FOR HOUSEHOLD PURPOSES AND ITS VARIABILITY IN A RURAL HOUSEHOLD

Tomasz Bergel[1], Tomasz Kotowski[1], Olga Woyciechowska[1]

[1] Department of Sanitary Engineering and Water Management, University of Agriculture in Kraków, al. Mickiewicza 24/28, 30-059 Kraków, Poland, e-mail: t.bergel@ur.krakow.pl

Received: 2016.03.16
Accepted: 2016.06.01
Published: 2016.07.01

ABSTRACT
The paper presents an analysis of daily water consumption for household purposes carried out within one year in a selected rural household. The study was undertaken because so far the guidelines for designing rural water supply systems have not been updated for a very long time and needed verification. It involved a comprehensive system for measuring water consumption equipped with automatic readers and data recorders. The research clearly showed that actual water consumption was much lower than that provided in the current guidelines, and confirmed significant variability in water consumption for household purposes depending on the day of the week. Moreover, variability of water consumption within a year, determined by daily variation coefficient, was found to be much higher than that provided in the guidelines.

Keywords: rural household, water consumption, household purposes, variability of water consumption

INTRODUCTION

There are many countries, both rich and poor that do not pay enough attention to proper water and wastewater management, either for economic or cultural reasons. In a rich emirate such as Dubai, water consumption per capita is about 500 $dm^3 \cdot I^{-1} \cdot d^{-1}$. In Europe, it is much lower. In Spain it amounts to 270 $dm^3 \cdot I^{-1} \cdot d^{-1}$, in France to 151 $dm^3 \cdot I^{-1} \cdot d^{-1}$, and in Germany to 129 $dm^3 \cdot I^{-1} \cdot d^{-1}$ [Kuczyński and Żuchowicki 2010].

In Poland, considering exceptionally low water resources as compared with other countries, water consumption should be a priority. Mean water consumption in 2014 amounted to 85 $dm^3 \cdot I^{-1} \cdot d^{-1}$ [GUS 2014], and was lower than in the Western Europe. As water consumption is steadily decreasing due to increasing water prices, water-saving devices or installation of water meters [Bartkowska 2014; Hotloś 2010; Kępa et al. 2013; Pawełek and Kaczor 2006; Satora and Milijanovič 2007; Usidus and Litewka 2013], maintenance problems appear in overdimensioned water supply systems. The need for verification and update of the parameters taken into account during designing new and conversion of existing water supply systems has been addressed by many researchers [Bartkowska 2014; Kępa et al. 2013; Pawełek and Kaczor 2006], as the parameters provided in the guidelines, particularly in the long outdated order of the Minister of Agriculture [Order... 1966] do not reflect the reality. However, it is important to underline that in fact the dataset that may be used for such verification is very limited. Very few studies have determined actual water consumption for household purposes [Pawełek and Bergel 2004, Bergel 2005]. Most studies by different authors reported actual water consumption per a conversion inhabitant (CI). This parameter accounts for household purposes but also for water used for all other needs of a household and sometimes even of an entire water supply system. These results are then incorrectly attributed to a single inhabitant (I) and constitute the basis for many comparisons and analyses that obviously result in incorrect and misleading conclusions.

This situation affects also the analysis of variability in water consumption. Water consumption is determined based on irregularity coefficients that should be taken into account during designing new and converting existing water supply networks, as they affect the network technical parameters. These coefficients have not been updated for a very long time and are still used by water supply system designers and the same parameters are also often used in the design of sewerage systems.

This paper presents an analysis of water consumption for household purposes and its daily variability in a selected rural household with an aim of building a new database and confirming the need to verify current guidelines.

MATERIALS AND METHODS

The study was conducted in one of the rural households in the village of Włostowice, Koszyce commune, Proszowice poviat, in the northern part of Małopolska province. The household was connected to a water supply and sewerage network. There were five permanent inhabitants and one (additional) person was present only over the weekends. The only exception occurred in June, when three of permanent inhabitants went abroad.

The study lasted from May 2011 to April 2012. Two water meters (Metron) recording water consumption with relative measurement error of +/- 2 % were installed in the household. The first meter, JS 2,5 17 was installed at water supply connection and recorded the total water consumption in the household. The second device, JS 1,5 17, was installed at the livestock building and recorded water uptake for other purposes. Water consumption was read automatically and recorded by Mini Log B registering device manufactured by Endress+Hauser. Water amount used for household purposes was calculated as the difference between total consumption and consumption for other purposes.

The study results were subjected to a statistical analysis with Statistica 12 software. The database included 365 records. The analyzed parameters included daily water consumption (D) and daily individual water consumption (I), i.e. water consumption per capita. Water consumption expressed as D and I was analyzed for individual months and days of the week.

RESULTS AND DISCUSSION

Daily water consumption for household purposes in the investigated household is presented in Figure 1.

The diagram shows considerable fluctuations in the size and variability of water consumption in the summer months as compared to the rest of the year. Daily water consumption ranged from 9.12 $m^3 \cdot month^{-1}$ in February to 13.3 $m^3 \cdot month^{-1}$ in July. The consumption decrease to 5.79 $m^3 \cdot month^{-1}$ in June was due to the absence of three out of five permanent inhabitants (Table 1).

Annual water consumption of 121.2 $m^3 \cdot year^{-1}$ was similar to that in two other houses inhabited by 3-person families that amounted to 118 $m^3 \cdot year^{-1}$ and 153 $m^3 \cdot year^{-1}$ [Pawęska et al. 2013]. Such a comparison allowed us to conclude that the inhabitants of the analyzed household were more economical with the use of tap water.

Average daily water consumption per capita in the investigated household was 65.5 $dm^3 \cdot I^{-1} \cdot d^{-1}$ and ranged from 57.8 in March to 81.3 $dm^3 \cdot I^{-1} \cdot d^{-1}$ in July (Table 1). These values were much lower than those from the previously mentioned two households, where water consumption was 110 $dm^3 \cdot I^{-1} \cdot d^{-1}$ and 140 $dm^3 \cdot I^{-1} \cdot d^{-1}$ [Pawęska et al. 2013]. A study covering 43 households within a single-family houses residential district in Koszalin reported average daily water consumption of 129.3 $dm^3 \cdot I^{-1} \cdot d^{-1}$ [Żuchowicki and Gawin 2013], and in a study concerning a single-family house in Kraków this parameter was 146.7 $dm^3 \cdot I^{-1} \cdot d^{-1}$ [Bergel, Pawełek, 2004]. Calculated average daily water consumption per capita was by about 35% lower than 100.0 $dm^3 \cdot I^{-1} \cdot d^{-1}$ provided as a benchmark value in the regulation of the Minister of Infrastructure [Regulation…2002] for apartments equipped with water and sewerage system (water supply, toilet, bathroom, local source of

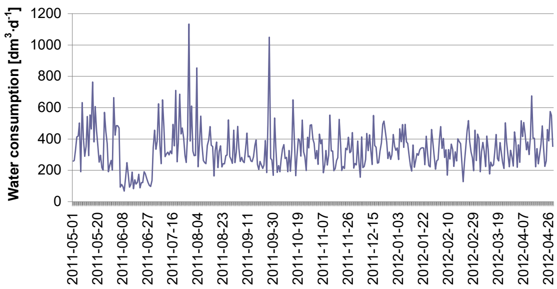

Figure 1. Daily water consumption within the analyzed period

Table 1. Water consumption in the analyzed household

Month	Water consumption		
	[m³·month⁻¹]	average daily	
		[dm³·d⁻¹]	[dm³·I⁻¹·d⁻¹]
May	11.69	377.1	72.1
June	5.79	192.9	70.1
July	13.30	428.9	81.3
August	10.46	337.4	64.0
September	9.53	317.6	60.5
October	10.45	337.0	62.8
November	9.35	311.8	58.7
December	10.37	334.5	63.5
January	10.14	327.1	61.9
February	9.12	325.8	61.5
March	9.48	305.8	57.8
April	11.53	384.4	72.1
Average	**10.10**	**332.1**	**65.5**

hot water, connection to sewerage network). This difference is even more pronounced when the calculated average daily water consumption is compared with 125-160 $dm^3 \cdot I^{-1} \cdot d^{-1}$, i.e. the range provided in the referenced Order of the Minister of Agriculture. Here, this parameter would account for only 41-52% of these values.

Precise characteristics of the recorded water consumption was established by means of statistical analysis. It included 356 records of daily water consumption (D) and daily individual water consumption (I). Table 2 presents basic descriptive characteristics of the analyzed data set.

The variance for D parameter was clearly higher than that for I parameter. This shows that daily water consumption was more varied than individual consumption. The results of skewness indicated right skewed distribution for both parameters. Kurtosis results demonstrated considerable density of results around average values. Graphical representation of D and I parameter distribution is presented in Figure 2 in a form of histograms. The figure is supplemented with graphs showing deviation from normal distribution for individual parameters (upper right corners).

Visual assessment of the distribution type showed it was normal or nearly normal for both parameters (D and I). Normality of the resulting distributions was evaluated with the tests investigating their similarity to normal distribution, i.e. Kolmogorov–Smirnov (K-S), Lilliefors, and Shapiro-Wilk (S-W) tests. However, all the tests demonstrated different than normal distribution for both parameters (D and I). This was probably due to the presence of anomalous values that shifted the distribution type towards the right skewed one.

Most methods of statistical inference require data sets characterized by a normal distribution. Therefore, Box-Cox transformation was employed to normalize the distribution of the analyzed data. Following the transformation, the data

Table 2. Descriptive characteristics of water consumption

Parameter	Number	Average	Median	Minimum	Maximum	Variance	Stand. dev.	Skewness	Kurtosis
D	365	332.1	320.0	67.0	1133.0	18154.7	134.7	1.5	5.5
I	365	65.5	61.0	25.4	226.6	569.2	23.9	2.3	10.1

Table 3. Normality test (Box-Cox transformation)

Variable	max D	K-S p	Lilliefors p	S-W	p
D	0.043	p > 0.20	p > 0.01	0.987	1.98E-03
I	0.028	p > 0.20	p > 0.20	0.997	6.15E-01

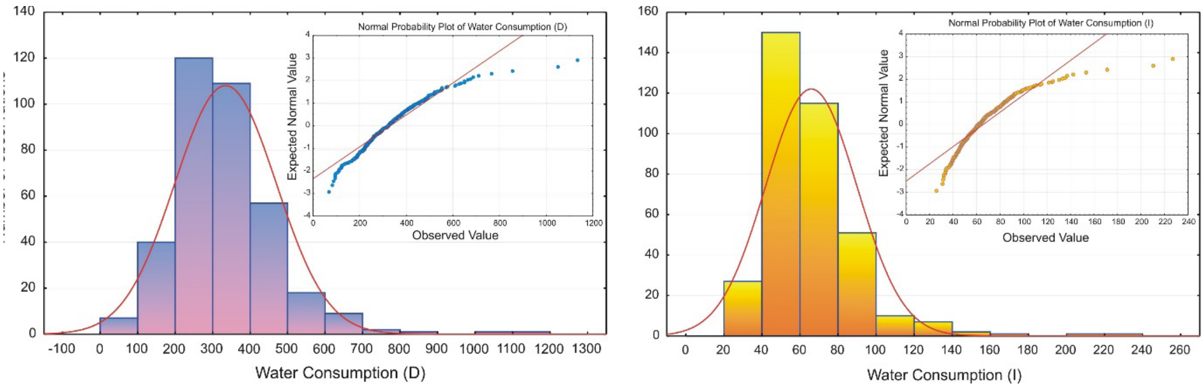

Figure 2. Histograms depicting water consumption and graphs representing deviation from normal distribution

were again subjected to Kolmogorov–Smirnov, Lilliefors, and Shapiro-Wilk tests. Box-Cox transformation yielded normal distribution only for I parameter, and the most powerful test, i.e. Shapiro-Wilk test, clearly indicated normal distribution for I parameter (Table 3).

Considering the above, it was concluded that the analyzed data were characterized by normal and non-normal distribution and nonparametric tests were used for further statistical inference. The data were then subjected to Kruskal-Wallis and multiple comparison tests.

Kruskal-Wallis test is a nonparametric equivalent of a one-way analysis of variance (ANOVA) and the interpretation of the test results is based on calculated ranks. D and I parameters were analyzed using seven grouping variables (independent) that represented individual days of the week.

The results of Kruskal-Wallis test amounting to 58.47 for D and 32.77 for I, and the test probability level of $p = 0.0000$ (for both parameters) allowed for rejection of the null hypothesis assuming no significant differences between water consumption represented by D and I parameters on different days of the week. In other words, variability of water consumption represented by D and I parameters was significantly different on individual days of the week. To demonstrate this variability, multiple (bilateral) comparison analysis was performed. It involved multiple comparisons of average ranks for each pair of groups. This analysis showed statistically significant differences in the variability of water consumption D between Saturday and other days of the week. Similar findings were also reported in other studies [Bugajski and Kaczor, 2005], and they were most likely due to specific cultural conditions and the habits of the residents regarding hygiene. Furthermore, significant differences were found between Sunday and Tuesday, and this might be due to different number of inhabitants and their reduced activity after the weekend.

The results for individual daily water consumption were more variable. Statistically significant differences in this parameter occurred between Saturday, Sunday, Monday, and Tuesday, and between Friday, Monday, and Tuesday. Kruskal-Wallis test for I parameter indicated that the variability in individual water consumption might be due to variable work patterns of the household residents.

Figure 3 shows individual water consumption for an average week and its variability determined by daily variation coefficient N_d. Maximum water consumption per capita was observed on Saturday and it was 73.9 $dm^3 \cdot I^{-1} \cdot d^{-1}$, and minimum on Sunday when it was only 58.7 $dm^3 \cdot I^{-1} \cdot d^{-1}$. The highest water consumption in a single-family house investigated by Bugajski and Kaczor [2005] was also observed on Saturday but it was by 34% higher than that recorded in Włostowice and amounted to 111.8 $dm^3 \cdot I^{-1} \cdot d^{-1}$. Daily variation coefficient for individual days of the week ranged from 1.53 on Saturdays to 3.65 on Tuesdays and

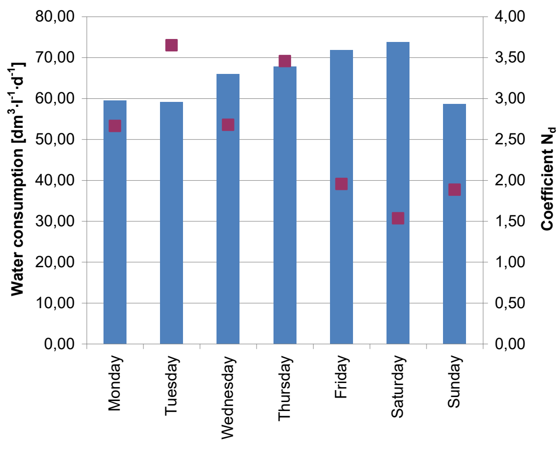

Figure 3. Weekly variability of daily individual water consumption

indicated lower water demand on the weekend than on the other days of the week.

Our analyses included also daily water consumption in different months of the year. Research methodology was the same as for water consumption on different days of the week. D and I parameters were analyzed using 12 grouping variables (independent) that represented individual months of the year. The results indicated significant differences in water consumption in different months. The multiple comparison test showed a distinctive structure of water consumption in June. This was undoubtedly due to the lowest daily water consumption resulting from the absence of three residents.

Differences between June and other months were also observed with regards to monthly water consumption and daily variation coefficient (Figure 4).

Daily variation coefficient for the entire study period was 3.41 and it was characterized by significant variations from 3.44 in June to 1.51 in January. Another study carried out in a single-family house in Kraków [Pawełek and Kaczor, 2007], also demonstrated high daily variation coefficient that ranged from 2.2 to 3.5, depending on the year of the study. The study by Bugajski and Kaczor [2005] reported N_d coefficient of 1.77, and it should be pointed out that, similarly to the household in Włostowice, the results for summer months were more variable than those for autumn and winter. The calculated N_d coefficient of 3.41 was over 2.5 times higher than the coefficient provided in the Order of the Minister of Agriculture amounting to 1.3 [Order ... 1966].

CONCLUSIONS

1. The research carried out in the selected rural household unequivocally confirmed that both the size and variability of actual water consumption for household purposes differed significantly from the values provided in the guidelines.
2. Individual water consumption with average around 65.5 $dm^3 \cdot I^{-1} \cdot d^{-1}$ confirmed the efforts towards economical and rational water management reported also by other authors.
3. Changes in the nature and functions of rural households are accompanied by changes in water demand. They are reflected e.g. by daily variation coefficient, the value of which (3.41) was over 2.5 times greater than that provided in the guidelines.
4. Statistical inference demonstrated significant differences in the variability of water consumption (both daily D, and individual I) for different grouping variables, i.e. days of the week and months of the year.
5. The study indicated the need for further and extensive research, the final aim of which should be a development of new guidelines for designing water supply systems in rural areas.

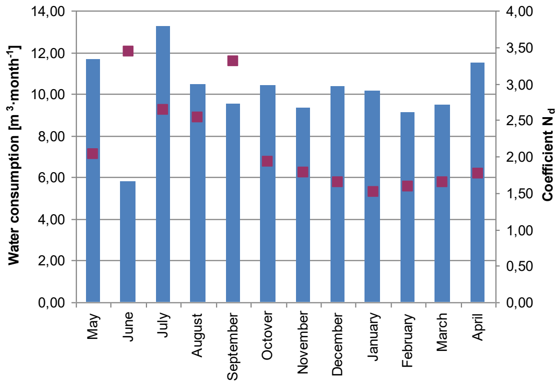

Figure 4. Monthly variability in water consumption

REFERENCES

1. Bartkowska I. 2014. Dynamics of water consumption changes in a tourist resort. Journal of Ecological Engineering, 15(4), 46–54.
2. Bergel T. 2005. Optymalizacja doboru jednostkowego odpływu ścieków jako warunek prawidłowego funkcjonowania wiejskich systemów kanalizacyjnych. Gaz, Woda i Technika Sanitarna, 11, 23–26.
3. Bergel T., Kaczor G. 2007. Wielkość i nierównomierność poboru wody przez pojedyncze gospodarstwa wiejskie. Infrastruktura i Ekologia Terenów Wiejskich, nr 1, 125–136.
4. Bugajski P., Kaczor G. 2005. Struktura zużycia zimnej i ciepłej wody w gospodarstwie jednorodzinnym. Infrastruktura i Ekologia Terenów Wiejskich, nr 2, 17–26.
5. Główny Urząd Statystyczny. 2015. Infrastruktura komunalna w 2014 r. Informacje i opracowania statystyczne, Warszawa.
6. Hotloś H. 2010. Badania zmian poboru wody w wybranych miastach Polski w latach 1990–2008. Ochrona Środowiska, 32(3), 39–42.

7. Hotloś H., Głowacka J., Kołodziej A. 2012. Zmienność poboru wody w systemie wodociągowym Wrocławia. Ochrona Środowiska, 34(4), 23–28.
8. Kępa U., Stępniak L., Stańczyk-Mazanek E. 2013. Analiza zużycia wody i zmienność rozbiorów dla obszaru zasilania Kawie Góry na terenie miasta Częstochowy. Rocznik Ochrona Środowiska, 15, 2546–2562.
9. Kuczyński W., Żuchowicki W. 2010. Ocena aktualnej sytuacji w zaopatrzeniu w wodę w Polsce na tle sytuacji w świecie. Rocznik Ochrona Środowiska, 12, 419–465.
10. Order No. 1 of the Minister of Agriculture as of 5 January 1966 on the guidelines for the calculation of water demand in rural settlement units (J. of Constr., No. 3 of 1967, item 13). [Zarządzenie nr 1 Ministra Rolnictwa z dn. 5.01.1966 r. w sprawie wytycznych do obliczeń zapotrzebowania na wodę w wiejskich jednostkach osadniczych (Dz. Bud. nr 3 z 1967 r., poz. 13)].
11. Orzechowska M. 2011. Rzeczywiste zużycie wody w warunkach wiejskich na przykładzie wybranych wodociągów. Inżynieria Ekologiczna, 26, 206–212.
12. Pawełek J., Bergel T. 2004. Specyfika zużycia wody na przykładzie wybranego gospodarstwa. Inżynieria Rolnicza 2(57), PAN Warszawa, 135–148.
13. Pawełek J., Kaczor G. 2006. Jednostkowe zużycie wody w gospodarstwie domowym w 8-letnim okresie obserwacji. Infrastruktura i Ekologia Terenów Wiejskich, 2/1, 159–170.
14. Pawełek J., Kaczor G. 2007. Charakterystyka zużycia wody w domu jednorodzinnym w dziesięcioletnim okresie badań. Gaz, Woda i Technika Sanitarna, 9, 22–24.
15. Pawęska K., Bawiec A., Włodek S. 2013. Wstępna analiza średniego zużycia wody w jednorodzinnych gospodarstwach domowych. Infrastruktura i Ekologia Terenów Wiejskich, No. 1/IV, 171–179.
16. Regulation of the Minister of Infrastructure as of 14 January 2002 on determining the average standards of water consumption (J. of L. as of 31 January 2002). [Rozporządzenie Ministra Infrastruktury z dn. 14.01.2002 r. w sprawie określenia przeciętnych norm zużycia wody (Dz. U. z dn. 31.01.2002 r.)].
17. Satora S., Milijanovič E. 2007. Wielkość zużycia wody przez użytkowników wodociągu w Jordanowie. Infrastruktura i Ekologia Terenów Wiejskich, nr 1, 205–214.
18. Usidus D., Litewka A. 2013. Rozbiory wody w miejscowości Ustka. Rocznik Ochrona Środowiska, 15, 1070–1085.
19. Żuchowicki W., Gawin R. 2013. Struktura zużycia wody w budynkach jednorodzinnych. Rocznik Ochrona Środowiska, 15, 924–929.