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ANALYSIS OF WATER CONSUMPTION IN 2014-2017 IN TORUŃ

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Abstract

This work analyses the variability of water consumption in Toruń over the years 2014–2017. The difference between the largest annual water consumption (2016) and the smallest (2014) was 13.2%. Higher consumption values typically occurred in the warm half-year, except in 2015. The lowest values occurred in the winter months (February), and the highest in the summer months (from June to August). The largest day-to-day variations in water abstraction were recorded at Easter and Christmas. There were differences between the average water consumption on particular days of the week, with the largest differences being between Saturdays (the highest value) and Sundays (the lowest value). Average unit water consumption was in the range of 58.2 to 67.3 $dm^3 \cdot M^{-1} \cdot d^{-1}$. On the basis of multiple regression analysis, a set of the factors with the greatest impact on the daily variability of water consumption in the city (in the warm half-year) was indicated. These factors include: evaporation, day of the week, humidity and maximum temperature.

Keywords: water consumption, inflow per inhabitant, meteorological conditions

INTRODUCTION

Since the beginning of the 1990s, a downward trend in water consumption has been observed in Poland (Roman *et al.* 2001, Kłos-Trębaczkiewicz and Osuch-Pajdzińska 2005, Heidrich and Jędrzejkiewicz 2007) Despite the significant decrease in water consumption (of about 30%), the breakdown of use has not changed significantly for many years. About 75% of water is used for manufacturing purposes, 15% for municipal purposes, and only 10% for hydration. In urban areas, the volume of water consumption decreased by almost half (by 48% over the years 1990–2016), with its structure also remaining without major changes (production targets 76%, municipal 23%).

The observed decrease in water consumption in cities was caused by many factors. One of the most important ones was the introduction of a free market economy, which resulted in closed or limited production in many industrial plants, which were also the largest consumers of water (Piasecki and Marszelewski 2016). The way of calculating the water consumption fees has also changed, through universal metering (water meters). In addition, in the analysed period, water wastage was significantly reduced due to the installation of high-quality dredging equipment and the modernisation of sanitary sewers and equipment. This has significantly improved the consumption of water by individual households (Piasecki *et al.* 2016). Hotloś (2010) additionally indicates a number of local factors that have played a different role in individual water supply systems. These include the size of the city and its functions (e.g. administrative, industrial, spa), the standard of sanitary equipment for apartments, lifestyle and work, residents' habits and hydro-meteorological factors.

The aim of the work is to analyse the variability of tap-water consumption in the city of Torun (210 thousand inhabitants) in 2014–2017. The analysis of the results includes the variability of water consumption for particular seasons, months and days of the week. Additionally, a group of factors determining the variability of water consumption in the warm half-year period (Apr–Sept) was indicated.

MATERIALS AND METHODS

Data from Toruńskie Wodociągi Sp. z o. o. for the years 2014–2017 was used to analyse the volume of water injected into the water supply network. In the further part of the article, this quantity is identified with the consumption of water, which allowed for the calculation of unit consumption. The obtained values are slightly overstated in relation to actual values, because they do not take into account, for example, losses caused during water transmission in the

network, or failures. On the basis of the collected data, the average water consumption for the following periods was calculated:

- meteorological seasons (spring: March 1 to May 31, summer: June 1 to August 31, autumn: September 1 to November 30, winter: December 1 to February 28) (Michalik 2016),
- calendar months,
- individual days of the week (public holidays were categorised as Sundays),

The analysis also determined the dependences between the amount of water injected in the warm half-year (months Apr–Sept) and the day of the week and selected meteorological parameters (sum of atmospheric precipitation, air temperature [mean, minimum and maximum], wind speed, air humidity, sunshine, evaporation and vertical exchange). In the case of the "day of the week" variable, a binary method was used to code information, as follows:

- Monday, Tuesday, Wednesday, Thursday, Friday, Saturday: value = 0,
- Sunday or public holiday: value = 1.

The evaporation was calculated based on the Penman–Monteith method (Allen 2000). Meteorological data came from the IMGW-PIB meteorological station in Toruń. Correlation coefficients were determined for individual explanatory variables and an explanatory variable (daily data). A multiple regression analysis was also conducted to verify the combined effect of selected factors on water consumption (daily data). The study adopted a significance level of 0.01.

Currently, Toruń is supplied water from three main water intakes: surface water on the Drwęca River, infiltration water from the Drwęca Valley in Jedwabno and groundwater in Mała Nieszawka. There is also a small ground intake in the Czerniewice district. The length of the water supply network in Toruń is currently 584.1 km (including main networks 100.2 km, distribution networks 366.6, and water connections 110.1), which has tripled since the early 1990s. At present, almost all inhabitants of the city are connected to the municipal water supply system (Piasecki and Marszelewski 2014). Despite the significant expansion of the infrastructure and the increase in the number of individual customers, a downward trend in the amount of water consumed has been being observed for several years. Its volume in 2017 amounted to 12.8 million m^3, which was about 33% of water injected in 1990. The reason for such a large drop is the changes in socio-economic conditions mentioned in the introduction.

RESULTS

In particular years of the analysed period, significant discrepancies in water consumption in Toruń were observed. The highest value was recorded in 2016 (over 13.6 million m^3), and the lowest in 2014 (approximately 11.8 million m^3). A similar change was noticed in the unit consumption of water in the ab-

sence of a significant change in the number of inhabitants. The data collected in Table 1 indicate the lack of dependence between the amount of water injected and the sum of atmospheric precipitation on an annual basis. In individual years the course of water consumption was similar in monthly and daily terms. The lowest values occurred in February, and the highest in the summer months from June to August. Every year, a very large daily decline was recorded for the Easter and Christmas holiday periods (Fig. 1).

Table 1. Sum of atmospheric precipitation and amount of water injected into the Toruń water supply system

Year	Water [thous. m^3]	Unit water consumption [$dm^3 \cdot M^{-1} \cdot d^{-1}$]	Sum of rainfall [mm]
2014	11 829.4	58.2	423.9
2015	12 890.0	63.6	526.8
2016	13 628.3	67.3	628.0
2017	12 789.0	63.1	409.9

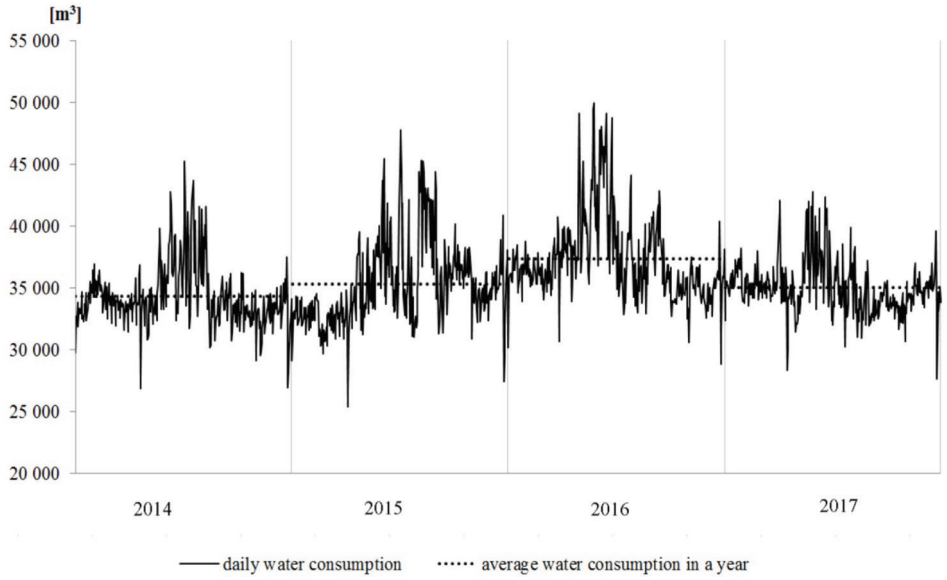

Figure. 1. Daily water consumption.

Each year, the average amount of water consumed did not vary much between days from Monday to Friday. The highest values were observed on Sat-

urdays whereas the lowest on Sundays. At the same time, there were significant differences between the average water consumption on particular days of the years 2014 and 2016 (Fig. 2). The largest differences, exceeding 9%, occurred between the days of the week in those two years.

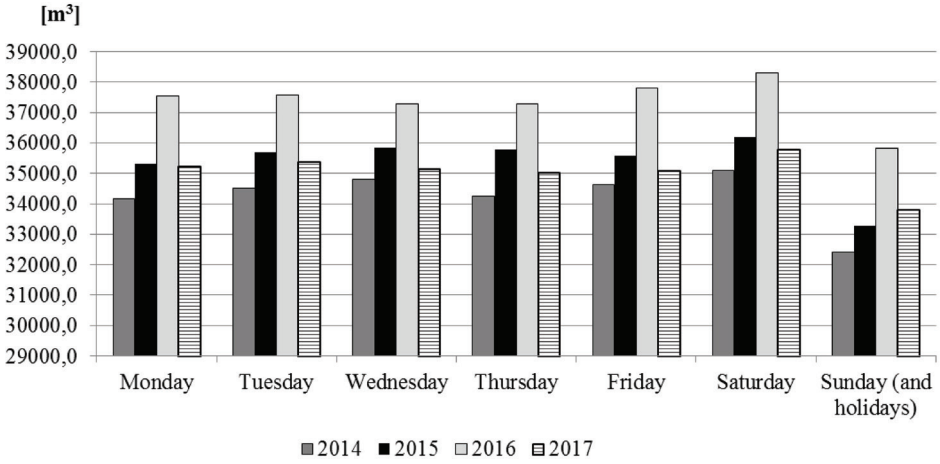

Figure 2. Average water consumption on individual days of the week in 2014–2017.

A similar regularity for particular days of the week was found when analysing the warm and winter half-years separately. The only difference is in the amount of consumption, which was higher, ranging from 1 700 to 2 700 m^3 (Table 1). The largest increases (of over 2 500 m^3) were found for Monday, Tuesday and Friday, and the lowest for Sunday.

Table 1. Average water consumption on particular days of the week of the warm and cold half-year in 2014–2017.

Day of the week	Warm half-year	Cold half-year	Difference
Monday	36 952.9	34 181.9	2 771.0
Tuesday	37 029.2	34 526.6	2 502.6
Wednesday	36 757.3	34 741.2	2 016.1
Thursday	36 791.4	34 774.6	2 016.7
Friday	37 033.6	34 513.6	2 520.0
Saturday	37 349.5	35 360.5	1 989.0
Sunday and public holidays	34 503.8	32 771.8	1 732.0

In each of the analysed years, water consumption was found to be similar across meteorological seasons (Fig. 3). The difference was in the range of several percentage points. The biggest share of water consumption was recorded in the summer season (from 26 to 27%), and the smallest in winter (from 23 to 25%).

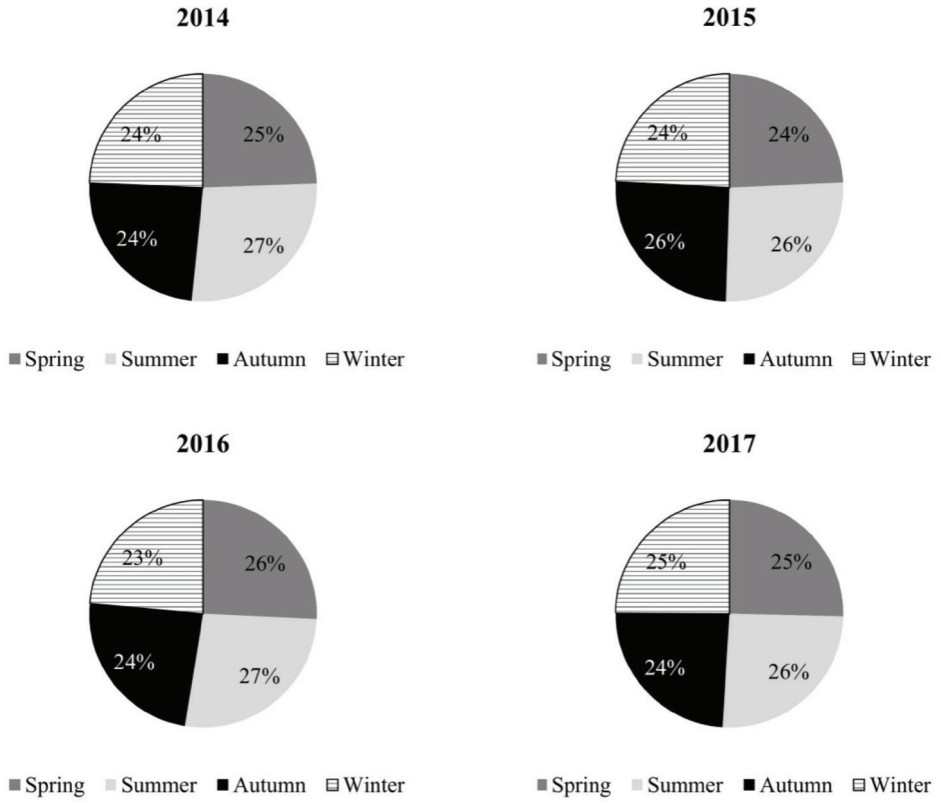

Figure 3. Percentage of water consumption by meteorological season

Correlation analysis showed that water consumption correlated most strongly with evaporation and air humidity (R above 0.6), and most weakly with wind speed. At the same time, a strong correlation was found between several pairs of explanatory variables (including average, minimum and maximum temperatures). It should be noted that small correlation coefficients do not necessarily mean that the dependent variable does not depend on the explanatory variables. This state of affairs may suggest that a more complicated relationship exists between them, and that only a group of independent variables analysed together can be strongly correlated with the dependent variable. Therefore, in the analysis of multiple (stepwise) regressions, all explanatory variables were used,

except those in mutual strong correlation. Finally, the following set of explanatory variables was used: temperature max., precipitation, humidity, sunshine, evaporation, day of the week.

Table 2. Correlation coefficients

	1	2	3	4	5	6	7	8	9
Water consumption	0.464	0.197	0.511	-0.148	-0.029	-0.616	0.565	0.663	-0.245

where: 1 – temperature mean, 2 – temperature min., 3 – temperature max., 4 – precipitation, 5 – wind, 6 – humidity, 7 – insolation, 8 – evaporation, 9 – day of week.

Multiple regression analysis resulted in model (1), in which the variables were: evaporation, day of the week, humidity and maximal temperature. Table 3 contains the main statistics of the explanatory variables of the constructed model. The most important variable in the model is evaporation, which explains 44% of the observed variability of water consumption. Adding the "day of the week" variable (x2), improves the quality of the model and increases the level of explained variability to about 50%. The addition of the other two variables (x3 and x4) increases the level of explanation to only a very small extent. Due to the value of partial and semi-particle correlation, it is advisable to leave both variables in the model.

$$W_{con} = 38838.85+0.182x_1-0.24x_2-0.31x_3+0.21x_4 \quad (1)$$

where: x_1 – evaporation, x_2 – days week, x_3 – humidity, x_4 – temperature max.

Table 3. Selected statistics of explanatory variables

Variable	Statisics					
	Multiple R^2	R^2change	Partial correlation	Semi-partial correlation	tolerance	p
x_1	0.663	0.440	0.097	0.066	0.130	0.009
x_2	0.704	0.056	-0.333	-0.239	0.998	0.000
x_3	0.724	0.028	-0.237	-0.165	0.277	0.000
x_4	0.732	0.012	0.172	0.118	0.316	0.000

DISCUSSION

In Toruń, as in most cities in Poland, a significant decrease in water consumption in recent years has increased pressure on effective management of the water production and distribution process. One of its more important elements

should be a detailed recognition of factors affecting the variability of water consumption in different time intervals. The volume of water consumption in Toruń has remained low in recent years, which is confirmed by the indicator of unit consumption (in the range of 58–67 $dm^3 \bullet M^{-1} \bullet d^{-1}$). In the literature for various cities, a fairly diverse range of values of the said indicator is given, while in most cases it ranges from a dozen to several dozen cubic decimeters higher (Bugajski and Kaczor 2005, Pawełek and Kaczor 2006, Osuch-Pajdzińska and Roman 2008, Bugajski and Satora 2009, Rak *et al.* 2012, Pawełek and Wojciechowska 2015, Szeląg and Malczewska 2016).

The observed variation in the amount of water consumed on individual days of the week results from the normal cycle of societal activity and the activity of economic entities. The higher water consumption on Saturdays is explained by the increased demand for water on the part of households, among others for cleaning works, and in the warm half-year also for watering domestic gardens and lawns. Comparable relationships were also found by other authors in relation to the urban centres they examined (Rak *et al.* 2007, Chmielewski *et al.* 2009, Usidus and Filon 2011, Studziński *et al*. 2014).

It has been shown that the relationship between meteorological conditions and water consumption is quite complex and is limited in principle to the warm half-year. This applies in particular to the sum of atmospheric precipitation, a factor whose impact on water consumption would seem obvious. It turns out that this relationship is very small, especially on an annual and monthly basis. The reason why it is so is the specificity of this parameter related to its time irregularity (e.g. in some months, rain fell on one day only). Analyses of the relationship between selected meteorological parameters and water consumption in other cities showed slightly different relations (Struckmeier 1975, Hotloś *et al.* 2012, Hotloś 2013, Kolendo 2016). This should be explained by the influence of local climatic conditions (e.g. less variability of precipitation sums), as well as a different structure of water abstraction related to the character and function of the city (e.g. administrative, industrial, spa, agricultural).

The analysis of multiple correlations identified a set of factors determining the variability of water consumption in Toruń. For discussion it is possible to leave the humidity, maximum temperature and evaporation in the variable model. The significant impact of the first two variables on the pairing value is undisputed. Leaving a variable (pairing) is justified by the fact that it is a result of the influence and interdependence of other meteorological parameters, including insolation, wind speed and average temperature.

CONCLUSIONS

Knowledge of the volume of water intake is important in forecasting water consumption, as well as in the planning of production, distribution and maintenance processes of equipment and infrastructure. The analysis of the results of water consumption in Toruń led to the following conclusions:

- There is a large variation in the volume of water consumption in Toruń over time (comparing annual values, seasonal values, monthly values or daily values). The largest unevenness of water consumption occurs in the warm half-year (April–September).
- Twice a year, there is a clear drop in water consumption associated with the Easter and Christmas holiday periods.
- Average unit water consumption was in the range of 58.2 to 67.3 $dm^3 \cdot M^{-1} \cdot d^{-1}$. The lowest value occurred in 2014, and the highest in 2016.
- There was a lack of relationship between the annual amount of water consumption and the sum of atmospheric precipitation. This does not mean that precipitation has no impact on water consumption. The relationship between variables exists, but should be looked for in shorter time intervals (e.g. the day) and ought to take into account other factors (e.g. season, evaporation, day of the week).
- It has been shown that meteorological conditions have an impact on the amount of water consumed in Toruń, but this applies mainly to the warm half-year. In the cold half of the year, sudden changes in water consumption were associated only with the occurrence of public holidays.
- Factors determining the variability of water consumption in Toruń in the warm half-year are: evaporation, day of the week, humidity and maximum temperature.
- Toruń stands out against other cities of similar size, very small share of industry in the total consumption of water. It is also an example of a typical academic city. A smaller number of students in the holiday season is compensated by a large number of tourists.

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