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DAILY WATER DEMAND VARIATIONS IN THE BIALYSTOK WATER DISTRIBUTION SYSTEM IN LIGHT OF CHOSEN ECONOMIC AND ENVIRONMENTAL CONDITIONS

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ABSTRACT: The study presents the analysis of water consumption in Bialystok in north-eastern Poland in the years 2007–2013. It has been shown in the study that demand for water during a week is varying and it fluctuates. A detailed analysis of water consumption on individual days of the week and public holidays is presented. Individual consumption per capita and daily water consumption irregularity coefficients were estimated. In the analysed period, the highest average daily water demand was recorded on Saturdays (43,129 m^3), and the lowest on Sundays (37,712 m^3). Moreover, the impact of economic and environmental factors on the process under study has been characterized in the study. In Bialystok, the price of water increased by 42% in the years 2007-2013, with the inflation rate in the country at 119.2% in those years. It is also presented the influence of maximum daily temperature and precipitation sum on daily water consumption on working days and Saturdays, as well as separately, on Sundays and public holidays.

KEY WORDS: water demand irregularity, daily water use, air temperature, rainfalls, water price

Introduction

The analysis of water consumption is one of the elementary issues in planning, design, and operation of water supply systems. It is aimed at capturing the relationships and typical regularities of the process under examination (Siwon et al., 2006). The analysis of the amount of water squashed into the water supply system in urban areas is particularly important in the light of the downward trend in the amount of water used, which continues over the years (Klos, 2013). The observed downward trend is the result of transformations taking place in the technical, social and economic spheres of life (Babel at al., 2014; Their, 2015).

The factors determining the above-mentioned changes include: the reduction of failure rate, gradual network modernization and its monitoring with the use of IT systems (Trębicka, 2013). Decreasing water consumption is also a consequence of a significant increase in the price of water in recent years. What is more, decreasing water use is also results of an increase in the population's salary, which, among other things, makes it possible to have access to water-saving household appliances (Arbues et al., 2003). Demographic factors, i.e. population numbers and migrations of the population related to, among others, with holiday season, also affect water consumption (Hotlos, 2013; Studziński at al., 2014).

In addition, environmental factors also influence the level of both annual, monthly and daily demand, i.e. the variability of meteorological conditions, in particular air temperature (average and maximum) and the sum of precipitation (House-Peter, Chang, 2011; Yasar et al., 2012). The research and analysis of the influence of meteorological factors on the variability of water intake has been conducted for years. However, due to the distinctive characteristics of the water distribution system and different local climatic conditions, it is advisable to conduct such research in each water supply system (Hotlos, 2013).

The aim of this paper is to describe the characteristics of daily demand for water on particular days of the week, as well as the irregularity of the examined process with the indication of the regularity having a considerable influence on the amount of water pumped into the water supply system. Unit consumption per an inhabitant was estimated and coefficients of irregularity of daily water consumption were determined. The above-mentioned characteristics were the starting point for the analysis of economic and environmental factors influencing the daily demand for water in Bialystok urban water supply network. The analysis considered the price increase for water supply and sewage disposal as well as two climatic factors, i.e. the maximum daily air temperature and the daily sum of precipitation.

Daily water use in Bialystok

Bialystok, with a population of about 300 thousand inhabitants, is the largest city in north-eastern Poland. The city functions as the administrative, economic, scientific and cultural centre of the Podlasie Voivodship. Bialystok is the largest academic and scientific hub in the region. The city offers education opportunities for about 43 thousand students. The leading industries in the city's economy are: food processing, electrical engineering, machine industry, plastic processing, textiles, wood building materials (https://en.um.bialystok.pl/274-charakterystyka/default.aspx).

Based on data obtained from Wodociągi Białostockie Sp. z o. o. (Water Supply Pipelines of Bialystok Ltd.) for the years 2007-2013, daily volume of water pumped into the water mains of Bialystok was analyzed. In this paper, the example time series of the daily water demand (for the years 2007 and 2013) are shown in figures 1 and 2. The following regularities should be indicated when characterizing the time series of the analyzed process for particular years. The first characteristic feature is the noticeable seasonality per week (s=7). In all the characterized years, at the beginning of the year, roughly to about 90-100 days, there is a very similar distribution of demand for water with only the mentioned seasonality of the week observed. Then, about between 90th and 100th day, there is a temporary (1-2 days) dramatic drop in water consumption, which is a consequence of moveable Easter holidays.

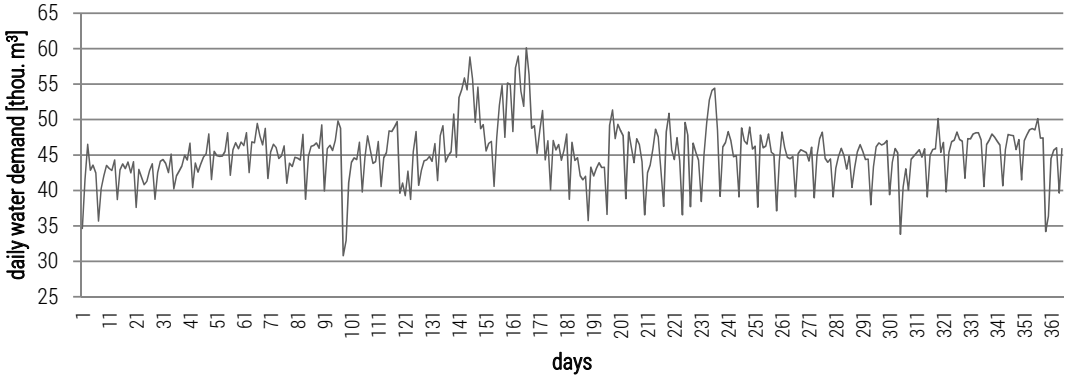

Figure 1. Daily water demand in 2007

Source: author's own work based on data from Municipal Water and Sewage Company in Bialystok.

Subsequently, in most of the analyzed time series, a significant deviation from regular seasonality is also observed between 121 and 123th day of the year. These are public holidays, on 1-3 May, where the demand for water is decreasing. In the following months, there is a certain irregularity. The period

from May to August is characterized by an increase in water consumption in relation to the remaining months and, it is worth noting that each year the course of the chart line differs slightly. Weekly seasonality is impaired by other factors. According to the author's earlier research (Kolendo, 2016a; Kolendo, 2016b), weather conditions played a significant role during that period, which will also be analyzed later in this paper.

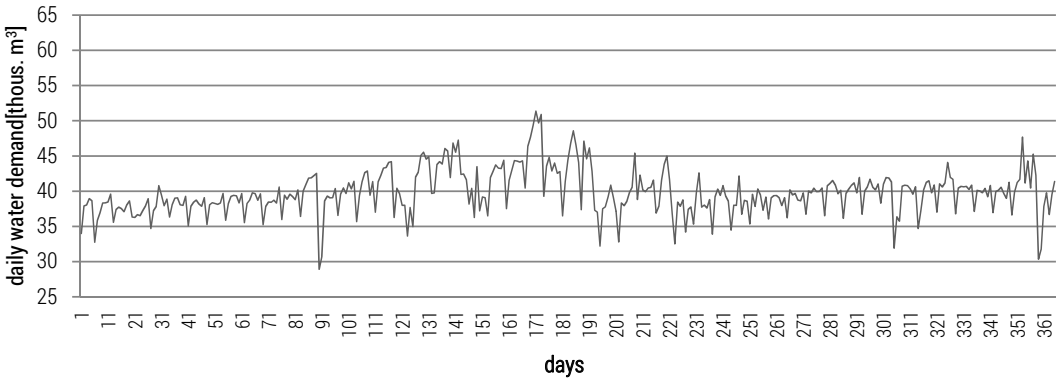

Figure 2. Daily water demand in 2013

Source: author's own work based on data from Municipal Water and Sewage Company in Bialystok.

When analyzing further elements of time series of the daily water demand, from about September (that is from 244th element of the series) a clear weekly regularity is noticeable, like that observed at the beginning of the year. Therefore, the influence of random factors, such as weather conditions, is decreasing. By the end of the year, therefore, until the end of the annual daily water consumption series, a deviation from the average values is recorded on 305th day of the year (1 November). Significant deviations from the average level of the time series also occur at the end of the year. At first, there is a significant increase in water consumption on the 357 and 358 days of the year, followed by a sharp decline. The lowest levels are recorded on the 359 day or 25 December (Christmas Day). This is a very characteristic moment in the analyzed series. This regularity shall be repeated in all the years of characterization. The detailed development of the time series from 22 to 31 December of the years 2007-2013 is presented in figure 3.

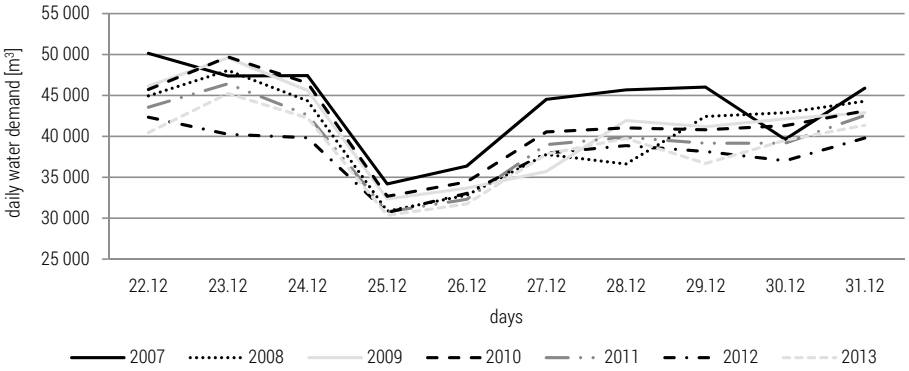

Figure 3. Daily water demand between 22.12 and 31.12 in each year

Source: author's own work based on data from Municipal Water and Sewage Company in Bialystok.

The analysis of the time series of the daily water demand in the years 2007-2013 allows us to determine a day characterized by maximum and minimum water consumption. Minimum daily water consumption in the period from 2007 to 2013 was recorded on March 31, 2013, on Easter Sunday. On that day 28,904 m^3 of water was pumped into the water supply system. The maximum daily water consumption was on 15 June 2007, on Friday, and amounted to 60,111 m^3. This confirms that the smallest water partitions occur on public holidays, while the largest partitions occur on summer days.

Mean daily water demand and its irregularity

As it was presented in the works (Kolendo, 2016a; Kolendo, 2016b), in which the time series of annual and monthly water demand were analyzed, there is a clear decreasing trend in water consumption in Bialystok. The above-mentioned process is also observed by analyzing daily water demand.

The difference between the average daily water consumption in 2013 and 2007 is 5446 m^3/d, which represents 12% of the average in 2007. The population is quasi-fixed, so the q_i indicator showing water consumption per capita is also decreasing. It is worth noting that with lower water consumption the irregularity of water consumption is also decreasing. Although this is not a linear trend, it can generally be stated that smaller fluctuations in water consumption were observed in the time of lower water demand (table 1).

Table 1. Water demand in 2007-2013 and its irregularity

Year	$Q_{dśr}$ [m³/d]	Population [no. of individuals]	q_i [m³/M*d]	Q_{dmax} [m³/d]	Q_{dmin} [m³/d]	N_d
2007	45 227	307 315	0,147	60 111	29 327	1,33
2008	43 741	307 638	0,142	57 056	26 176	1,30
2009	42 470	308 439	0,138	53 709	21 339	1,26
2010	42 096	308 432	0,136	52 730	21 801	1,25
2011	41 484	308 997	0,134	53 516	22 738	1,29
2012	40 356	309 864	0,130	49 835	19 701	1,23
2013	39 781	310 466	0,128	51 377	22 473	1,29

Source: author's own work based on data from Municipal Water and Sewage Company in Bialystok.

Table 2 shows the average water production per a weekday over the period of the years 2007-2013. On each day of the week, there is a declining trend, with the biggest decrease in average water consumption between 2007 and 2013 was recorded on Fridays (nearly 14%).

Table 2. Water production in particular days in years 2007-2013

Day	Water production [m³]							Mean [m³]
	2007	2008	2009	2010	2011	2012	2013	
Monday	45 441	43 608	42 846	42 051	41 387	40 358	39 856	42 225
Tuesday	45 995	44 903	43 740	43 035	42 284	41 235	40 319	43 071
Wednesday	46 145	45 191	43 994	43 191	43 011	41 097	40 838	43 358
Thursday	46 019	44 976	43 206	43 077	42 591	40 875	40 652	43 057
Friday	46 151	44 319	42 513	42 781	41 846	40 732	39 863	42 601
Saturday	46 803	44 331	43 347	43 099	42 198	41 425	40 719	43 129
Sunday	40 029	38 812	37 628	37 426	37 057	36 839	36 210	37 712

Source: author's own work based on data from Municipal Water and Sewage Company in Bialystok.

The highest average daily water demand in the analyzed period is on Saturday (43 189 m³) and the smallest is on Sunday (37 712 m³). However, it should be emphasized that the average amount of water pumped into the water supply system from Monday to Saturday varies slightly between days (table 2). This finding is also confirmed by the small standard deviation values for all days (from 3 233 to 3 549 m³).

Economic and environmental aspects

The author's previous research shows that many factors influence the demand for water in years, months and subsequent days (Kolendo, 2016a; Kolendo, 2016b). One of the economic aspects, conditioning especially the decreasing tendency of the characterized process that has been observed for years, is the price for water supply and sewage discharge. In the years between 2001 and 2013, Pearson's correlation coefficient for the annual sum of water pumped into the water mains and the price for water supply and sewage disposal in Bialystok was -0.95 (Kolendo, 2016a), which highlights the strong correlation of these variables.

According to the research conducted by the Supreme Chamber of Control in 2016, charging the costs of water supply and sewage disposal in Poland to household budgets, expressed in percentage of the total budget, is one of the highest in the European Union and has already reached a level above which the EU principle of price availability of services will be violated (http://multiconsult-polska.com/ceny-wody-w-polsce-najwyzsze-w-eu).

In the area served by Water Supply Pipelines of Bialystok Ltd., there was also a significant increase in the prices of the service. Table 2 presents a comparison of inflation in Poland according to data from the Central Statistical Office and price increases for water supply services and sewage disposal in Bialystok in the years 2007-2013. The following analysis is based on price levels and inflation in 2007, where it is at the level of 100 percentage points. According to the analysis, the increase in the price of water in the analyzed period, amounting to 142%, is more than double the inflation rate in (119.2%). Similar dependences were noted, among others, in Dębica (Rak et al., 2007), Stalowa Wola (Studziński et al., 2014) and in most of the provincial cities (http://multiconsult-polska.com/ceny-wody-w-polsce-najwyzsze-w-eu).

Meteorological factors also influence the variability of the overall water abstraction and consumption by its users of the urban water supply system (Arbues et al., 2003; House-Peters, Chang, 2011; Hotloś, 2013; Kolendo, 2016a), including to the greatest extent the air temperature and the intensity of rainfall. To determine the causal link of increased fluctuations in water consumption in the period from May to August and to capture certain regularities, the values of daily water demand (in m^3) were compared with meteorological parameters, i.e. the maximum daily temperature (in °C) and daily sum of rainfall (in mm). Meteorological data for Bialystok station (WMO index – 12295) were obtained OGIMET service (www.ogimet.com), due to the large amount of data, detailed analysis and characterization of the influence of meteorological factors was performed for data of 2013.

Table 3. Inflation in Poland and changes of water prices in Bialystok in 2007-2013

Year	Inflation [%]	Changes of water prices in Bialystok [%]
2007	100	100
2008	104,2	106
2009	107,7	120
2010	110,3	126
2011	114,6	135
2012	118,3	142
2013	119,2	142

Source: author's own work based on data from Central Statistical Office of Poland and Municipal Water and Sewage Company in Bialystok.

Many studies have shown that the impact of meteorological conditions on water consumption is recorded only in the spring and summer months (from May to August) (Hotloś, 2013; Kolendo, 2016b), which is also confirmed by the "disturbed" seasonal cyclicity of water consumption as seen in figures 1 and 2. In the present study both the influence on the process of average daily temperature and maximum daily temperature was considered. A much larger correlation was noted considering the maximum daily value of this factor. In addition, the greater influence of the change in the maximum daily temperature changes occurs at higher values of this parameter, i.e. in warmer months (it should be specified in which).

Water demand is also affected by the migration of the population (a school year, an academic year, holidays, public holidays). Therefore, to make the assessment to be more accurate, it was decided to consider the analysis of water demand in each month from May to August as separate periods and not as a single spring/summer season in total. Despite generally higher air temperature in July and August, water consumption is lower. The factors other than meteorological, such as students' departure from the city or the population's departure during the holiday season, have an impact here.

The studies were also conducted considering the variability of water intake in the weekly cycle. Due to the relatively balanced water consumption from Monday to Saturday these days were treated as one group, while Sunday and public holidays were analyzed separately.

As shown in the table below (table 4), the average maximum air temperature in the indicated four months ranges from 20.1°C to 24.5°C. From Monday to Saturday in all the analyzed periods, the influence of the maximum daily temperature is quite strongly correlated with the daily water consumption ($r \in <0,62;0,75>$). As the air temperature increases, the demand for water

also increases. Water consumption on Sundays and other public holidays is considerably lower (by 12-15%) than on weekdays and Saturdays. This is a consequence of the reduction in water consumption by residents, industry and public institutions. On Sunday and public holidays, the relationship between water intake and temperature is similar, although correlation rates are in most cases lower than on the remaining days, and in July even inconsistent with general knowledge. This is due to the fact that the analyzed data series for these days are small and it is difficult to draw general conclusions based on a few observations in the group.

Table 4. Mean water use, meteorological parameters and correlation coefficient

Month	Days	Mean water use [m³]	Mean maksimum temp [°C].	Rainfalls [mm]	Correlation coefficient [*]	
					Temperature [°C]	Rainfalls [mm]
May	Monday-Saturday	42 877,46	21,28	80,10	0,70	-0,37
	Sunday and Holidays	37 651,14	20,06	24,00	0,63	-0,64
June	Monday-Saturday	44 634,92	23,33	30,40	0,62	-0,17
	Sunday and Holidays	38 051,20	23,14	33,10	0,89	-0,10
July	Monday-Saturday	41 526,48	23,49	63,10	0,69	-0,26
	Sunday and Holidays	35 298,25	24,53	26,60	-0,64	-0,64
August	Monday-Saturday	39 676,42	23,58	64,10	0,75	-0,40
	Sunday and Holidays	34 563,80	23,80	0,00	0,74	-

Source: author's own work based on data from Municipal Water and Sewage Company in Bialystok and OGIMET.

The precipitation or lack of rainfall have also some impact on the daily water demand. The occurrence of prolonged rain-free periods in the spring-summer period causes an increase in water consumption, for example used to water public greenery, allotment gardens or to sprinkle streets and squares.

Figure 4 shows that during precipitation of more than 10 mm, water consumption is decreasing, but it is difficult to present the statistical impact of total precipitation on water consumption. In the conducted analysis (table 4) for most of the analyzed data sets, there are no statistically significant dependencies. This is due to the sizeable number of rain-free days or days with rainfall below 10 mm, which represents 93% of working days and Saturdays in the period between May and August 2013.

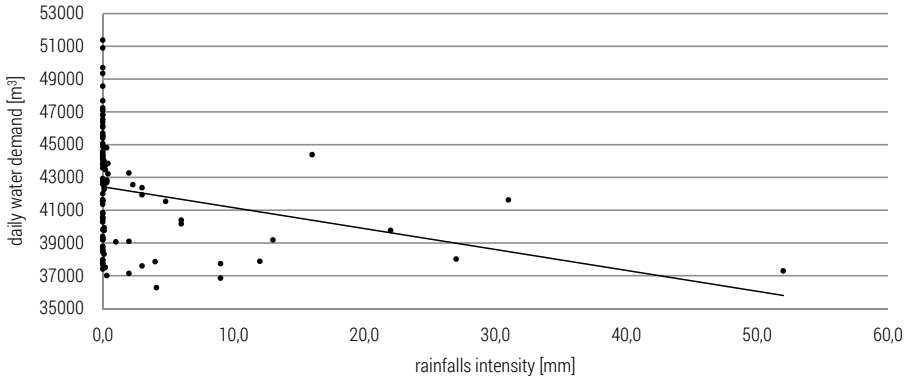

Figure 4. Daily water demand and rainfalls intensity (working days and Saturdays, 2013)

Source: author's own work based on data from Municipal Water and Sewage Company in Bialystok and OGIMET.

Conclusions

The paper indicates that the process of daily demand for water in Bialystok municipal water supply system is characterized by a weekly seasonality, which is disturbed several times during the year by the occurrence of public holidays, and in the period from May to August a significant contribution of random factor was also noted. In 2007-2013, the highest average daily demand for water was recorded on Saturdays (943 129 m^3), while the lowest demand for water was recorded on Sundays (37 712 m^3). Analysis conducted in Spain also show clear difference in the demand profile for the different days; namely, Saturdays are clearly different from Sundays (Herrera et al., 2010).

The quantity of water pumped daily into the water mains is determined, among others, by changes in water prices and local climatic conditions. The decreasing tendency, which has been going on for many years, is the result of a significant increase in the price of water, which in the years 2007-2013 was twice as high as the national inflation rate. Moreover, based on the collected data, the influence of population variability on water abstraction has been demonstrated. This process became visible in July and August, when water consumption is decreasing due to the departure of residents and students from Bialystok during their holidays and holiday breaks.

The statistical analysis of 2013 data shows that in the months from May to August there is a significant correlation between water consumption and maximum daily air temperature. The largest correlations were obtained on weekdays and Saturdays in May and August (r=0.70 and 0.79 respectively). The large variety of factors influencing the amount of water pumped into the

water mains and the overwhelming number of rain-free days mean that the influence of the amount of rainfall is sometimes imperceptible. A significant impact maximum daily air temperature and occurrence of rainfalls on daily water demand present also international studies (Bougadis et al., 2005; Yasar et al., 2012; Babel et al., 2014).

Literature

Arbues F., Garcia-Valinas M.A., Martinez-Espineira R. (2003), *Estimation of residential water demand: a stete-of-the-art review*, "The Journal of Socio-Economics" No. 32, p. 81-102

Babel, M.S., Maporn, N., Shinde, V.R. (2014), *Incorporating future climatic and socioeconomic variables in water demand forecasting: A case study in Bangkok*, "Water Resources Management" No. 28, p. 2049-2062

Bialystok.pl. The official city portal, https://en.um.bialystok.pl/274-charakterystyka/default.aspx [25-01-2018]

Bougadis J., Adamowski K., Diduch R. (2005), *Short-term municipal water demand forecasting*, "Hydrological Processes" No. 19, p. 138-139

Central Statistical Office, http://stat.gov.pl/obszary-tematyczne/ceny-handel/wskazniki-cen/ [11-05-2016]

Herrera M. et al. (2010), *Predictive models for forecasting hourly urban water demand*, "Journal of Hydrology" No. 387, p. 142

Hotloś H. (2013), *Analiza wpływu czynników meteorologicznych na zmienność poboru wody w miejskim systemie wodociągowym*, "Ochrona Środowiska" No. 2, p. 57-61

House-Peters L.A., Chang H. (2011), *Urban water demand modeling: Review of concepts, methods and organizing principles*, "Water Resources Research" No. 47, W05401, doi: 10.1029/2010WR009624

Kłos L. (2014), *Dostępność do wody jako jeden z obszarów realizacji Milenijnych Celów Rozwoju*, "Ekonomia i Środowisko" No. 3(50), p. 167-175

Kolendo M. (2016a), *Wybrane czynniki kształtujące zmianę wieloletniego zużycia wody w miejskim systemie wodociągowym*, "INSTAL" No. 5, p. 55-61

Kolendo M. (2016b), *Czynniki ekonomiczno-środowiskowe w modelowaniu miesięcznego zapotrzebowania na wodę na przykładzie Białegostoku*, "Ekonomia i Środowisko" No. 2(57), p. 162-174

Multiconsult Polska, http://multiconsult-polska.com/ceny-wody-w-polsce-najwyzsze-w-eu/ [15-05-2016]

OGIMET, https://www.ogimet.com/index.phtml.en [20-05-2016]

Rak J., Tchórzewska-Cieślak B. (2007), *Analiza zużycia wody przez mieszkańców Dębicy*, "Zeszyty Naukowe Politechniki Rzeszowskiej. Budownictwo i Inżynieria Środowiska" No. 42, p. 113-121

Siwoń Z., Cieżak W., Cieżak J. (2006), *Analiza i prognozowanie szeregów czasowych krótkotrwałego poboru wody*, "INSTAL" No. 2, p. 44-49

Studziński A., Pietrucha-Urbanik K., Dąbek M. (2014), *Analiza zużycia wody w miejscowości Stalowa Wola*, "Czasopismo Inżynierii Lądowej, Środowiska i Architektury" No. XXXI (61,1/14), p. 323-332

Thier A. (2015), *Aksjologiczne, ekonomiczne i społeczne problemy gospodarki wodnej*, "Ekonomia i Środowisko" No. 3(54), p. 10-24

Trębicka A. (2013), *Modelowanie i prognozowanie systemów związanych z dystrybucją wody*, "Ekonomia i Środowisko" No. 4(47), p. 245-254

Yasar A., Bilgili M., Simsek E. (2012), *Water Demand Forecasting Based on Stepwise Multiple Nonlinear Regression Analysis,* "Arabian Journal of Science and Engineering" No. 37, p. 2333-2341