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DAILY CHANGES OF WATER DEMAND IN THE SINGLE WATER SYSTEM ZONE IN KRAKOW

ANALIZA PORÓWNAWCZA ZMIENNOŚCI POBORU WODY W WYDZIELONEJ STREFIE WODOCIĄGOWEJ NA TERENIE KRAKOWA

A b s t r a c t

The paper focuses on changes in water demand within the water supply zone in Krakow. The analyzed time periods include the 90s of the last century and the years 2007–2012. Based on measurements of the size and variability of water demand, changes in daily water consumption within the week were analyzed and compared with the reference distribution. Both the results and research methodology can be used to update the guidelines for design and simulation of the water supply systems operation.

Keywords: *water system*, *water supply system*, *water demand*

S t r e s z c z e n i e

Artykuł zawiera analizy zmian poboru wody na terenie wydzielonej strefy wodociągowej w Krakowie. Bazując na pomiarach wielkości i zmienności poboru wody z lat 90. ubiegłego wieku oraz z lat 2007–2012, dokonano porównania zmian o charakterze ilościowym oraz nierównomierności poboru w ciągu poszczególnych dni tygodnia i porównano zmienność z rozkładem referencyjnym. Przedstawione wyniki badań oraz metodyka działań mogą posłużyć do aktualizacji wytycznych w zakresie projektowania i symulacji funkcjonowania systemów wodociągowych.

Słowa kluczowe: *system wodociągowy*, *wodociąg*, *zapotrzebowanie na wodę*

The authors are responsible for the language.

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1. Scope

Over last two decades people's attitude to the general commodity such as drinking water has changed due to political, social and economic transformations. Consumers changed their approach from purely consumerist, lacking concern for the amount of used and often wasted water, to more efficient and conscious management of this increasingly expensive good. Apart from well-known and widely described changes (e.g. [1, 2]) related to water savings and lower consumption, other changes followed related to the daily distribution pattern. They result from the new style of functioning of a modern society, where people start work at 5 a.m. or about 11 a.m. or some time they do not leave the house at all, working home. The study investigates the above-mentioned changes and looks into water demand fluctuations by observing a specific group of customers, classified as multi-family housing. Then the results are compared with the histogram of water demand for this group proposed in [3]. Similar pilot study was previously carried out in years 1993–1994 for a group of recipients living in the same region; the final results have been summarized and presented in [4] and [5].

2. Region characteristic

All information about water demand magnitude and variability relate to a single zone of the Krakow water system, the Mistrzejowice District, located in the north-eastern part of the city. From the water supply perspective. Mistrzejowice is a separate, isolated and detached zone, supplied only by a single pressure tank, Silver Eagles, located on the outskirts of the Golden Age Quarter. This zone has no water supply reservoir, which could buffer a water intake and flatten a distribution of water demand variability. This means that the pressure tank capacity matches the total demand for water in this area. Water recipients mostly occupy multi-storey buildings (10–12 floors), developed as housing estates, typical for the Nowa Huta District. They can be classified as multi-family housing. Other water consumers fall into the category of "services" and their number as well as water demand

Fig. 1. Water supply system-black contour line marks pipes served by the Silver Eagle pressure tank: a) in 1993, b) in 2010

fluctuate around 1% of the total demand in the zone. There are no other water consumers in the analyzed zone (i.e. the industry). Therefore, it can be assumed that the zone is a fairly homogeneous one and can be considered entirely as a multi-family housing zone.

Data from the 90s described water demand within the network shown in Fig. 1a), while the recent data covered the expanded zone shown in Fig. 1b). Over last 20 years the zone significantly expanded furnished with new distribution pipes supplying water to newly constructed multi-family units. Despite the significant development of the network the actual structure of water recipients in the zone remains unchanged. Hence, it still can be considered as a homogenous and classified as a multi-family housing unit.

3. Data analysis

The measurement data from the years 2007–2012 have been acquired by the authors courtesy of the Krakow Water and Sewage Works (MPWiK). The data, for various reasons, does not cover the whole period, unfortunately. Some measurements had to be excluded due to failures of measuring devices (lack of reading or a constant reading over several hours or days). Others were rejected after visual analysis of the daily distribution curve. Such cases involved the days when the flow fluctuations strongly deviated from the average values and significantly altered the daily distribution pattern. It can be assumed that these were periods of major system failures observed within the analyzed zone. Since the paper focuses on analysis of variability of water demand for a separate group of customers, such failures may interfere with the analyzed variability. For this reason, both extreme daily distribution patterns and the ones too distant from the mean were rejected from the test sample.

The measurement data, as digital readings of instantaneous flow and pressure on the pressure line, were collected in the local computer. Flow measurements were carried out with the POWOGAZ 250 MW water meter while pressure was measured with a pressure transducer Aplisens PC-28; the readings were carried out every 15 minutes. The readings used as a reference material [5], were carried out every 10 minutes. In order to compare the two sets of measurements it was decided to interpolate the actual 15-minute values and extract the values with the 10 minute intervals. The data from the 90s and the recent data have been analyzed with the same dedicated application HSO, which was created in previous studies. This procedure allows for a closer look at the comparable factors by analyzing the same test environment.

4. Water demand characteristics

The entire dataset was segregated to identify the groups describing demand variability in the consecutive days of the week. For such groups of data quantitative calculations were carried out to describe characteristic values of water demand. Additionally, matching indicators were determined for the whole period. The results are summarized in Tab. 1 while Tab. 2 shows corresponding results for years 1993–1994, as comparison. Values Q_r^* ask for some additional explanations; they present the annual demand for water, assuming that the whole year consists only of the one particular weekday, for example Monday.

Table 1

Water demand throughout the week, March 2007–May 2012

	Number of days	Q_r^* [m³/year]	$Q_{d\max}$ [m³/d]	$Q_{dśr}$ [m³/d]	N_d	$Q_{h\max}$ [m³/h]	$Q_{hśr}$ [m³/h]	N_h
Monday	167	783,397	2,713	2,146	1.264	200	113	1.769
Tuesday	165	776,793	3,147	2,128	1.479	172	131	1.312
Wednesday	161	775,325	2,604	2,124	1.226	190	108	1.751
Thursday	164	776,359	2,574	2,127	1.210	168	107	1.566
Friday	162	793,836	3,261	2,174	1.499	183	136	1.347
Saturday	174	866,371	3,283	2,373	1.383	193	136	1.411
Sunday	176	792,402	3,163	2,170	1.457	184	131	1.396
Total	1,169	809,750	3,283	2,218	1.480	193	137	1.411

Table 2

Water demand throughout the week, February 1993–December 1994

	Number of days	Q_r^* [m³/year]	$Q_{d\max}$ [m³/d]	$Q_{dśr}$ [m³/d]	N_d	$Q_{h\max}$ [m³/h]	$Q_{hśr}$ [m³/h]	N_h
Monday	69	1,384,164	5,608	3,792	1.479	328	233	1.404
Tuesday	70	1,390,592	5,619	3,810	1.475	325	234	1.388
Wednesday	71	1,431,046	6,829	3,921	1.742	471	284	1.655
Thursday	70	1,414,197	5,634	3,874	1.454	337	234	1.436
Friday	73	1,417,930	6,109	3,885	1.573	376	254	1.477
Saturday	73	1,605,705	6,536	4,399	1.486	367	272	1.348
Sunday	72	1,381,241	5,491	3,784	1.451	321	228	1.403
Total	496	1,433,407	6,829	3,927	1.739	471	284	1.655

Comparing the average daily and annual values it can be seen that that over 20 years water demand has decreased by about 40%, despite of expansion of the existing network and a noticeable number of new connections (new multi-family housings). Such observation complies with a general trend that manifests itself in a decrease of water demand per capita [2]. Unfortunately, the lack of detailed information on the number of residents in the studied zone makes it impossible to determine an interesting indicator – a water demand per capita for housing developments. However, some approximate data were used to estimate its value in both periods.

Scarce data from the year 1993 shows that population in the region was about 8,300 people at that time. Therefore:

$$W_j = \frac{Q_{dśr}}{LM} = \frac{3{,}927\,[\mathrm{m^3/d}]}{8{,}300\,[\mathrm{people}]} = 437\left[\frac{\mathrm{dm^3}}{\mathrm{person \cdot d}}\right] \tag{1}$$

The value is substantially higher than the values assumed during that time (300 dm^3/person/d). Any attempts to estimate the value for the current data have also been very inaccurate. No information was available on a population density in this region; only the average population density for the Mistrzejowice District was available. In order to somehow use this information the authors determined the surface area of the zone and estimated a probable number of inhabitants:

$$LM = D \cdot F = 9,781\left[\frac{\text{pop. density}}{\text{km}^2}\right] \cdot 1.24\,[\text{km}^2] = 12,128\,[\text{people}] \quad (2)$$

$$W_j = \frac{Q_{d\acute{s}r}}{LM} = \frac{2,218\,[\text{m}^3/\text{d}]}{12,128\,[\text{people}]} = 183\left[\frac{\text{dm}^3}{\text{person} \cdot \text{d}}\right] \quad (3)$$

W_j is still very large, here. Current guidelines regarding water usage [6] assume the indicator value within the range of 80–160 [dm^3/person/d]). Such a large value (a rough estimate) may result from large water losses in this area, or poor estimation of the indicator, by assuming a lower number of inhabitants.

Comparing both analyzed periods with respect to N_d and N_h it may be noted that the coefficients decreased slightly. The differences are so small that they may be attributed to some in accuracies in data sampling. It is difficult to determine a well-defined trend line of changes based on the obtained results.

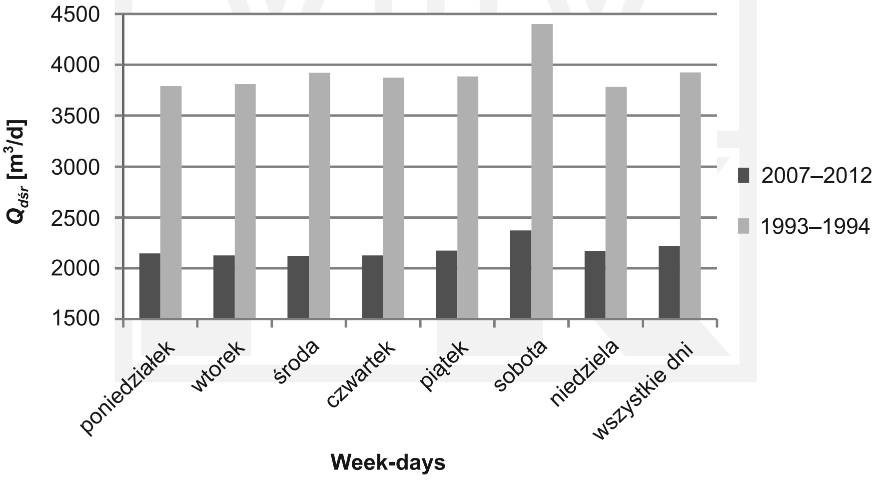

Fig. 2. Changes of $Q_{d\acute{s}r}$ during week-days for two data sets

Figure 2 compares $Q_{d\acute{s}r}$ in both analyzed periods, for each week-day. A daily trend line is maintained, however a significant drop in water demand in the area is observed, recently.

5. Fluctuation of water demand in specific time intervals

Two data sets (1993–1994 and 2007–2012) of fluctuations of water demand during each week day were compared with a distribution for a multi-family housing proposed by [3]. A series of graphs have been developed (Fig. 3.1–8), which illustrate the changes. Each graph includes the histogram of water demand proposed by [3] and the histograms developed from the data collected in years 1993–1994 and 2007–2012, including a standard deviation band for each hour of the day for all days (years 2007–2012 marked in black). Horizontal marks above and below the graph show the standard deviation for each hour. The gray dashed line marks histograms for years 1993–1994; solid dark-gray line shows a reference histogram.

When comparing samples from the years 1993–1994 and 2007–2012 some changes can be observed. A flattening of the evening peak as well as delay and spread of the afternoon saddle was observed on Monday to Friday, while at the same time higher flows occurred in night hours. Changes in the time interval of 6:00–23:00, involving reduction of graph dynamics, may result from greater diversification of the local community in terms of their activity and social functions. Popular human behaviors such as e.g. departure for work at 6:00–7:00 a.m., popular in 70s/80s of the last century, has evolved and got shifted to later hours. An increasing share of night flows may be associated with more accurate measuring devices that have been installed in recent years. Readings of night flows from the years 1993–1994 were incorrect due to a relatively high threshold value of water meters; they did not recorded flows lower than 12 m^3/h, what must be the cause of so low histogram value during this period.

Saturday and Sunday differ from the rest of the week; for both data sets the graphs look similar and do not follow the reference distribution.

Comparison of the average distributions for each day with the distribution proposed by [3], and considered as a reference, leads to the following conclusions:

– From 23:00 to 6:00 graphs looks very similar and overlap partially.
– On working days, the graphs differ from 6:00 to 23:00; morning rush hours are more stretched and flattened, if compared with a reference distribution. Also the middle day saddle is lifted and shifted by about two hours. The evening peak remains within the same hours, however it is more flattened.
– A reference graph, throughout its range, stays within the standard deviation boundaries determined for graphs for individual working days.
– Saturday and Sunday distributions are significantly different from the reference distribution and should be considered as functions describing a completely different human behavior.

The discrepancies between the reference distribution and the empirical distributions, however slight, may reflect the changes in the way the water system is used. It can be argued that over the past few years there have been significant changes in the functioning of urban communities. Growing social diversity in relation to activities outside home (different work hours and working part-time at home) is shown in the way the sanitation facilities are used at home. The symptoms of this change include flattening and delay of morning rush hours, as well as a delay and flattening of an afternoon saddle, if compared with the reference distribution. It is difficult to predict what might be the cause of a lower water demand during

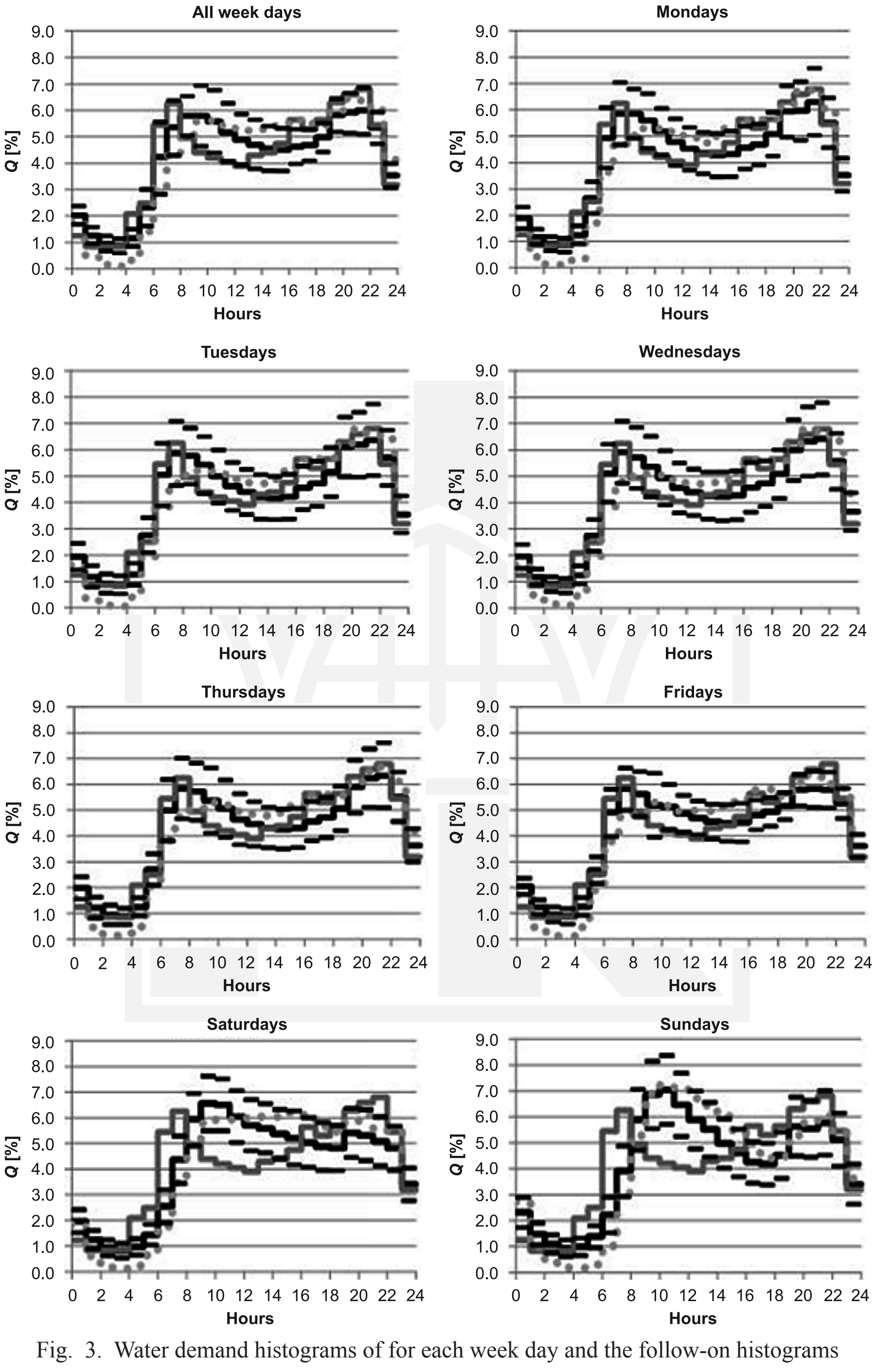

Fig. 3. Water demand histograms of for each week day and the follow-on histograms

the evening peak, though this phenomenon is clearly visible during each working day. Weekend distributions differ significantly from working days distributions with the highest water demand on Saturday and the lowest on Sunday. This observation is confirmed in both data sets. This may be related to the nature of the two days – Saturday is usually spent on chores while Sunday is a day of rest, also from the activities involving water use.

The empirical resultant distribution, describing the average weighted changes in the region does not differ significantly from distributions observed in working days. As such, it confirms the trend set by a reference distribution with all previously reported discrepancies. The empirical resultant distribution can be considered as standardization of human behavior in the analyzed water.

6. Seasonal variations of water demand

The measurement data set was used to estimate the seasonal changes in water demand. Hence, the annual measurement periods were divided into 3-months' intervals, which overlapped strongly with the seasons. Within these ranges summation of demands during available days were performed and then the average daily flow ($Q_{dśr}$) was determined for each season. The results are shown in Fig. 4. It can be seen that the greatest daily water demand was observed in winter, while the lowest in summer. The differences between the seasons are not large; they deviate from the average value by no more than 2%. A similar analysis was done for the data from years 1993–1994 and the results are shown in Fig. 5. During this period, an observed seasonal variability remained within a range of ±15% of the average value. It is difficult to explain and interpret this rather large quantitative difference between the two measurement periods, though the same trend in changes in water demand in different seasons was observed, for both cases. Strangely, the demand for water is lowest during the summer. It can be explained by the fact, that the analyzed water supply zone is located in a large city, which are usually deserted during summer vacations and total water demand in this period is the smallest.

The above relationships merely attempt to grasp a cycle of seasonal changes of the water demand in the zone with multi-family housing. Information obtained in this way, can be

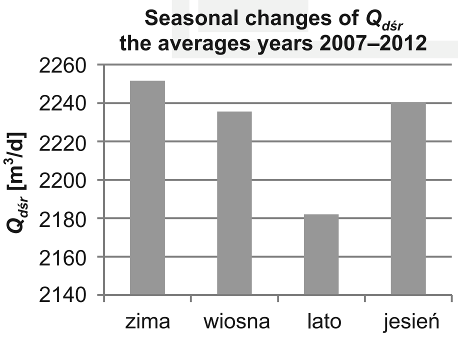

Fig. 4. Seasonal changes of $Q_{dśr}$; averages for years 2007–2012

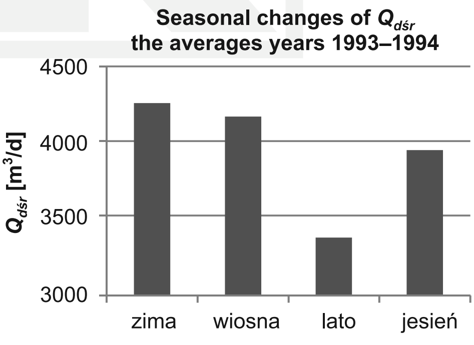

Fig. 5. Seasonal changes of $Q_{dśr}$; averages for years 1993–1994

further used only after more detailed studies. The studies would enable to determine seasonal peak and minimum flows, which are used to estimate water demand fluctuations, as well as in design or modeling of water supply systems.

7. Summary and conclusions

The obtained results can be used to identify some relationships in water demand within the water zone. The histograms of hourly variation generated for each week day as well as for the entire measurement period may be helpful when updating already old but valid guidelines for water demand programming within the multi-family housing zone.

Comparison of distributions of water demand variation over the past few years points out also at some changes, such as: a delay of the morning rush hours and the flattened southern saddle. They can be associated with major transformations that took place in our country over the past decades.

Analysis of seasonal variation showed different water demands at different seasons but the differences are rather small and difficult to interpret in a definitive way. Additional research on a larger test sample is necessary to get a more conclusive picture of these changes.

The research zone can be considered as homogeneous (in terms of land use) and classified as multi-family housing. The final results obtained by the authors do not allow for their propagation to other city zones, with a different land use. However, they may provide a good basis for further more detailed analysis; the methodology for the analysis has been developed during this project.

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