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# Causes and effects of water consumption drop by the population of cities in Poland - selected aspects

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**Abstract.** The article presents, with an example of four cities of various size, a phenomenon of a drop in water consumption by the city population in Poland. The paper draws on 1995-2012 official statistics. A significant decrease in household water consumption was observed, which refers to both the total water volume used by households as well as the average daily water consumption per resident. The article also determines the most essential factors affecting the amount of water consumed, out of which the price of water appears to be of the most significant one.



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## 1. Introduction

The access to running drinking water, at an adequate amount and quality, supplied directly to the individual consumer from the water supply network is one of the most essential indicators of the civilization development of the societies on Earth. In many regions water resources are already insufficient, as compared with the needs of the continuously growing number of consumers. For that reason in many countries, especially in Europe, a decrease in water consumption by residents over the recent years has been stimulated. The scale and the rate of that phenomenon, however, vary a lot. Searching for effective economic, technical, and technological tools with which water management will be more and more rational, is currently one of the most essential research directions (e.g. Wiliams, Suh, 1986; Nauges, Thomas, 2000; Rogers, 2002; Krauze et al., 2003; Flörke, Alcamo, 2004; Hoekstra, Chapagain, 2007; Goemansa et al., 2012). Specific nature of many European post-socialist countries, including Poland, involves the fact that a drop in the consumption of water in households was initiated rapidly after 1990, together with the shift from the centrally planned economy to the free market economy. Since then, both in cities and in rural areas, the downward trend continues to persist. Until recently, this phenomenon was generally considered to be a positive one. In the period before the political transformation, the water consumption was increasing from year to year despite a growing economic crisis. The very low, flat rates for water were fixed authoritatively with no reference to the actual costs of its uptake, distribution, and purification. This resulted in complete water mismanagement, which tolerated high percent losses of water pumped into the water supply network, due to leaking pipes and fittings. Water was then considered a free commodity and the only way to overcome the emerging deficits was by increasing its intake from diminishing surface and ground water resources. The process of realignment of water prices, initiated after 1990, radically reversed that trend and water uptake for water supply purposes in Poland decreased by an average of 30% and more within the last 20 years. It is indeed reflected in a change in the valid norms of water consumption in households. Although in the 1980s it was assumed that the mean daily water requirements per resident ranged from 0.2 to 0.3 $m^3$, including the dependence on the type of built-up and facilities of the premises, today it is assumed that the demand dropped to the range between 0.08 and 0.16 $m^3$. It means that water saving depends much on individual consumers (Pasela, Gorączko, 2013). Decreased water consumption in households should, however, be somehow limited, e.g., aiming at maintaining adequate life comfort or considering hygiene and health reasons. It seems that those are the factors which show that the downturn in Poland starts to be desired.

With the above in mind, it is justifiable to perform research to determine which of the socioeconomic factors have today the greatest effect on the individual water consumption in households, as well as what economic and technical effects result from its regular decrease. This problem used to be brought up in reference to all major cities of Poland, grouped into classes size-wise (Kłoss-Trębaczewska et al., 2000; Kłoss-Trębaczewska, Osuch-Pajdzińska, 2005; Heidrich, Jędrzejkiewicz, 2007; Gorczyca, 2013). Definitely less frequent are the papers on long-term changes in water consumption in specific cities (Holtoś et al., 2012; Kępa et al., 2013), or small groups of cities (Pasela, Klugiewicz, 2006; Hotloś, 2010; Żuchowicki, Telega, 2010). Such an approach, in turn, facilitates defining to what extent the operation of water supply systems is affected by local conditions.

## 2. Material and methods

The research involved the analysis of water supply and sewage systems of four cities of the Kujawsko-Pomorskie Voivodeship, administrative region of the 1st order" Bydgoszcz, Toruń, Włocławek, and Grudziądz (Fig. 1), which represent medium-sized settlement units (from 100 thousand to 400 thousand residents).

The basic statistics for the cities have been broken down in Table 1. All the cities are located in a close vicinity of the Vistula River, the biggest river in Poland, with an average flow rate ranging from 900 $m^3 \cdot s^{-1}$ in Włocławek to 1000 $m^3 \cdot s^{-1}$ in the Grudziądz region. Despite the closeness of such

abundant and day-to-day renewing water resources of Vistula River, none of the cities uses it to supply water to its residents. The instability of the flow rate in the Vistula River, long-term periods of extreme states (Gorączko, 2010; Gorączko et al., 2013), the width of the floodplain of the Vistula River many-fold greater than its riverbed, a considerable frequency of ice events on the river (Gorączko, 2013), intensive movement of the riverbed load and hence the riverbed bottom variation as well as, finally, a considerable pollution of the river, all those factors discourage from the intake of drinking water from the Vistula River to meet the requirements of the population of the cities. Basing the city water supply on local underground water resources has been technically easier and definitely more economically justifiable, which is true for Włocławek, Grudziądz, and Bydgoszcz. Likewise, Toruń and Bydgoszcz draw water from smaller rivers flowing into the Vistula River. Only in case of Toruń, the Vistula River has been used, but indirectly, through a set of wells as part of the infiltration intake.

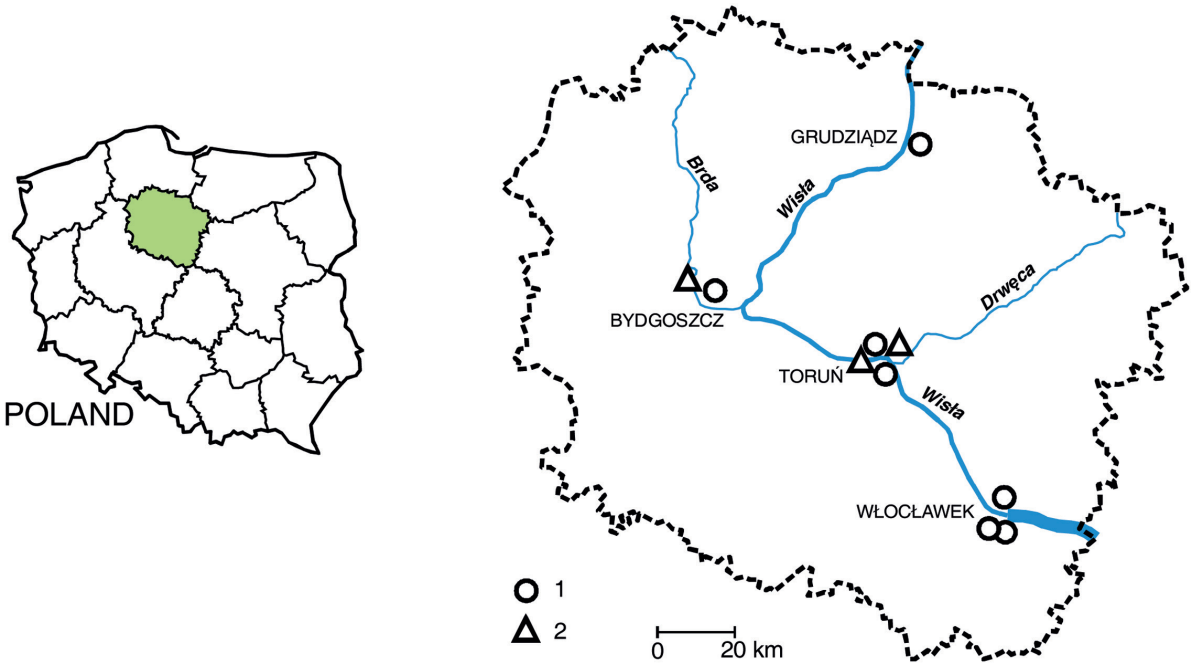


**Fig. 1.** Location of the cities analyzed in the Kujawsko-Pomorskie Voivodeship and defining the method of water intake to meet the water pipe requirements

Explanation: 1 – underground waters intake; 2 – surface waters uptake

*Source:* Authors' research

**Table 1.** Breakdown of selected statistics for the cities studied as of end of 2012

| Item | Unit | Bydgoszcz | Toruń | Włocławek | Grudziądz |
|---|---|---|---|---|---|
| City area | $km^2$ | 176 | 116 | 84 | 58 |
| Population | thous. | 361 | 204 | 115 | 98 |
| Unemployment rate | % | 8,6 | 9,6 | 21,3 | 22,6 |
| Water supply network length | Km | 608,4 | 352,0 | 241,3 | 189,1 |
| Sewage network length | Km | 668,4 | 466,9 | 183,5 | 198,3 |
| Water supply connections | Units | 19,547 | 9,293 | 6,863 | 4,506 |
| Sewage connections | Units | 20,770 | 11,072 | 6,851 | 3,788 |
| Maximum capacity of water intakes | thous.$m^3$ per day | 142 | 116 | 68 | 32 |
| Maximum sewage treatment plant /capacity | thous.$m^3$ per day | 123 | 90 | 40 | 26 |

*Source:* Central Statistical Office of Poland- Local Data Bank

Authors collected information published in the Local Data Bank of the Central Statistical Office for 1995-2012 period depicting the annual water consumption in households: mean daily water consumption per resident, user of water supply network: the level of the development of water and sewage infrastructure i.e. water and sewage networks' length: access of the city population to water and sewage network facilities (number of connections); as well as the number of residents, users of water and sewage networks. The data concerning water prices, which includes water production price and sewage treatment price are provided for in the resolutions, approval of tariffs for collective water supply, and collective sewage discharge, taken by the city council of respective units. This data is available to the general public. Based on the data collected for respective cities, it was possible to perform the analysis and to determine the relationship between respective parameters and water consumption in households. The results became a springboard for a discussion and study on the factors determining the amount of water consumption by residents of the cities as well as their interactions.

## 3. Results

### 3.1. Variations in water consumption to meet the city population requirements

Over the period studied in all the cities a significant decrease was recorded in the amount of water delivered by water-supply companies to meet the household requirements. The trend showed a variable dynamics, not always corresponding to the direction of demographic changes. Although today all across Poland we deal with a constant outflow of people from urban areas to suburban communes (Szymańska et al., 2009; Biegańska, Szymańska, 2013), in specific cases there occur some differences in the start date. For example, in Toruń over 1995-1999 the total consumption of water supplied to households decreased by as much as 30.6% despite the population increase by 3.6% at that time, whereas in Włocławek over 1995-1998 the respective values reached 24.7% and 0.2%. The cities differ from one another also in the moment at which the rate of the decrease of the total water consumption for household purposes grew most significantly. As for Bydgoszcz, similarly as Grudziądz, it was the year 2002, in Toruń it was reported in 2003, whereas Włocławek recorded it in 2004. In general, one can assume that starting from the early years of the 21st century, the total amount of water consumed by residents in the cities included in this study, was still decreasing. The rate, however, of that decrease was much lower than before. Throughout the period which was the subject of this analysis, in the biggest cities of the Kujawsko-Pomorskie Voivodeship, the amount of the water supplied to households decreased by an average of almost a half, from 38% in Grudziądz up to 58% in Bydgoszcz.

The tendency of changes in the total water consumption in the cities is well-correlated with the values of one of the most important indicators used for designing and evaluating the operation of water and sewage infrastructure, namely the unitary water consumption in households presented in the volume of water consumed by a statistical resident daily (Fig. 2). In the many-year period under study, in all four cites a considerable decrease in the value of that index was noted; in Grudziądz – 148%, Toruń – 122%, Włocławek – 94%, and in Bydgoszcz – 62%. The rate of the decrease in respective cases, however, varied a lot. The greatest disproportions among the cities were noted in mid 1990s when the values of the index ranged from 0,15 to 0,16 $m^3$ in Bydgoszcz and Włocławek, to more than 0,2 $m^3$ in Grudziądz and Toruń. However, in 2012 the mean value of the index for all the four cities was 0,087 $m^3$, ranging from about 0,08 $m^3$ in Grudziądz and Włocławek to about 0,09 $m^3$ in Toruń and Bydgoszcz. These values differ considerably not only from those recommended in the guidelines for designing water supply networks of 1978 (Wytyczne…, 1978) but also the currently binding Regulation of Minister of Infrastructure on defining the average water consumption norms of 2002 (Rozporządzenie…, 2002).

### 3.2. Effect of water supply prices on its consumption

The main reason of such a dynamic drop in water consumption by urban population in the last decade

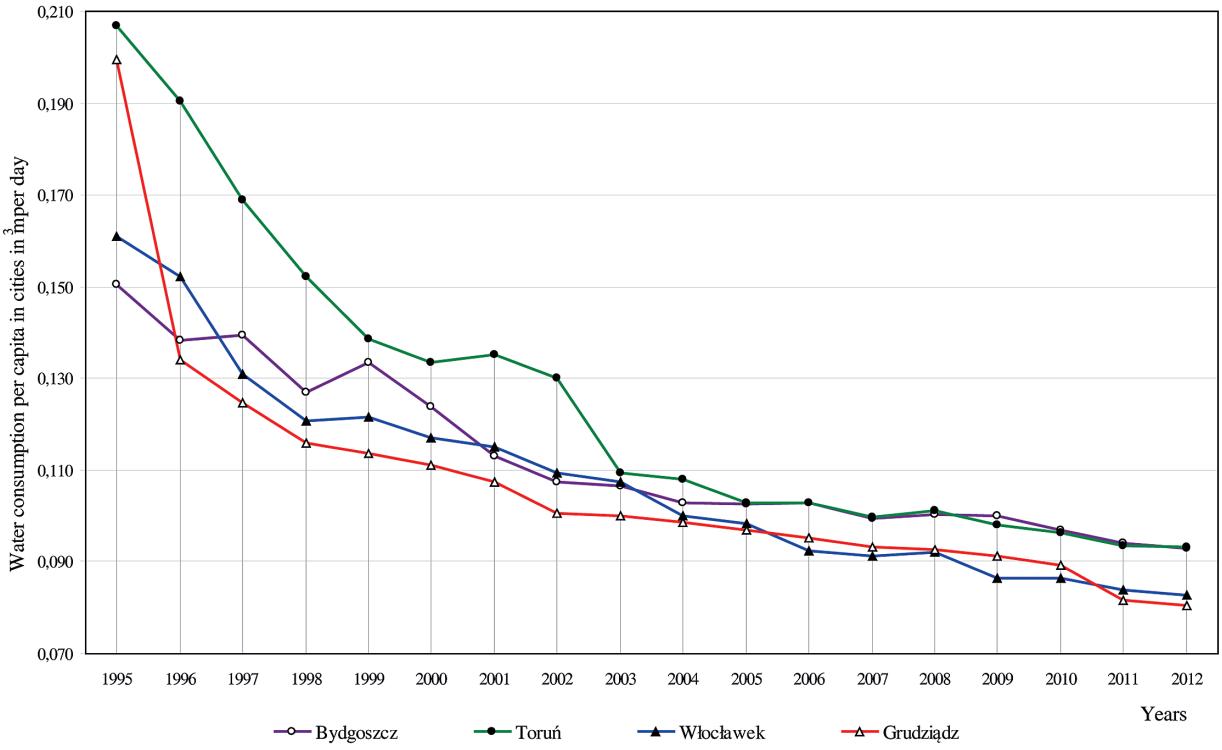


**Fig. 2.** Many-year variation in the value of the index of the mean daily water consumption in the cities analyzed

*Source:* Authors' own work

of the 20th century must have been caused by the changing method of settlement of individuals utilizing water supply services. Over that period, in most Polish cities there was a gradual shift from flat rates to the payments resulting from the real-life water consumption determined by the use of individual household water-meters. Due to a huge scale of the project and the bad habits present in the society, namely rational water management, the process of providing water-meters to households demonstrated a different intensity and its city-specific character. This directly affected the dynamics of the drop in water consumption in respective cities. The process was accompanied by a regular increase in the unitary payment for water consumption (price per 1m$^3$ from the water supply network). Once individual water-meters were installed in households, water consumers became definitely more willing to limit their water needs, in some cases even by more than 50% (Klugiewicz, Pasela, 2005; Nowakowski, 2010).

At present time water payments in urban areas in Poland most often show a multi-component structure, including the cost of supplying drinking water to households together with the cost of purifying water before it is supplied to the consumer. With an increase in the density of the water and sewage network, single-component payments for water itself are progressively less frequent (when the consumer does not use the city sewage system) or for sewage itself (when the household is based on its own water intake).

The payments are determined once a year, proposed by water supply and sewage companies operating in respective cities. The companies define indispensable revenues which will ensure the continuity of the collective supply of water of adequate quality and of adequate quantity as well as collective discharge and purification of sewage. The revenues should allow for covering justified costs related to water intake and uptake water, use, maintenance, and further development of water supply and sewage infrastructure as well as generate profits.

Although in mid 1990s in all four cities payment per 1m$^3$ of water (together with sewage) was about PLN 1, by 2012 it increased by an average of 870%, from 650% in Grudziądz to as much as

1200% in Bydgoszcz (Fig. 3), which means that the supply of pipe water belonged to the services the prices of which were increasing the most, even after considering the inflation ratio. At the beginning of the period analyzed (1995-1998) the dynamics of the increase in payments of water supply to households was similar in all four cities. Later changes took place in the most stable manner in Toruń; from one year to another they were increasing by an average of PLN 0.38. Water payments in Bydgoszcz were changing stepwise; periods of a dynamic growth (1999-2002 by an average of PLN 0.97 per 1 $m^3$ of water, and over 2006-2011 by an average of PLN 0.85) were divided by periods of stability (over 2002-2006 the price did not change and over 2011-2012 it increased only by PLN 0.05 1$m^3$ of water).

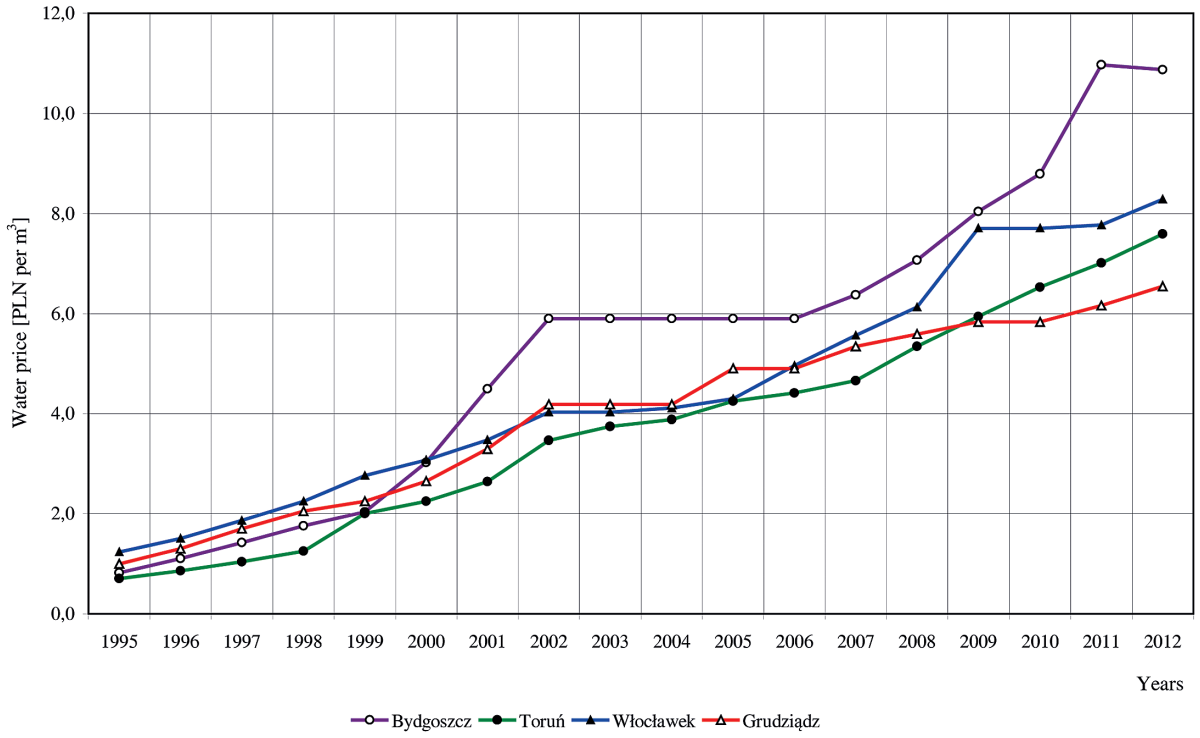


**Fig. 3.** Many-year variation in the amount of payments for water supply and sewage services in the cities analyzed

*Source:* Authors' own research

The cities are an adequate example of showing how local conditions can significantly affect the variation in fees for water supply services and their changes. One of the most important features is the quality of the intake water. Water from surface intakes, being the major source of water supply in Bydgoszcz and Toruń, requires the application of definitely more technologically advanced, and therefore more expensive, water treatment methods than in the case of the intakes of underground waters, which are most important in Włocławek and Grudziądz. This is related to a lower susceptibility of underground waters to pollution, both anthropogenic and natural, than the surface waters.

A significantly wide range of the amount of water payments made by individual consumers in respective cities is also considerably affected by the scale of investments connected with a further development and, mostly, modernization and use of water supply and sewage infrastructure. The highest costs in that respect were found in Bydgoszcz where, e.g., there was made a substantial alteration of water treatment system for the water from the Brda River intake; a municipal sewage treatment plant serving Bydgoszcz as well as the adjacent communes; and a sewage sludge incineration plant, which was built and, due to its high capacity, can be treated as a facility of regional importance. For example, the cost of in-

vestments launched by the Bydgoszcz water supply and sewage company from its own contributions, only after year 2000, was almost PLN 1,400 per resident. It is about 30% more than in Toruń and over seven times more than in Grudziądz in the same period. Therefore the differences in the value provided on the water supply and sewage services bills in those cities should not be surprising.

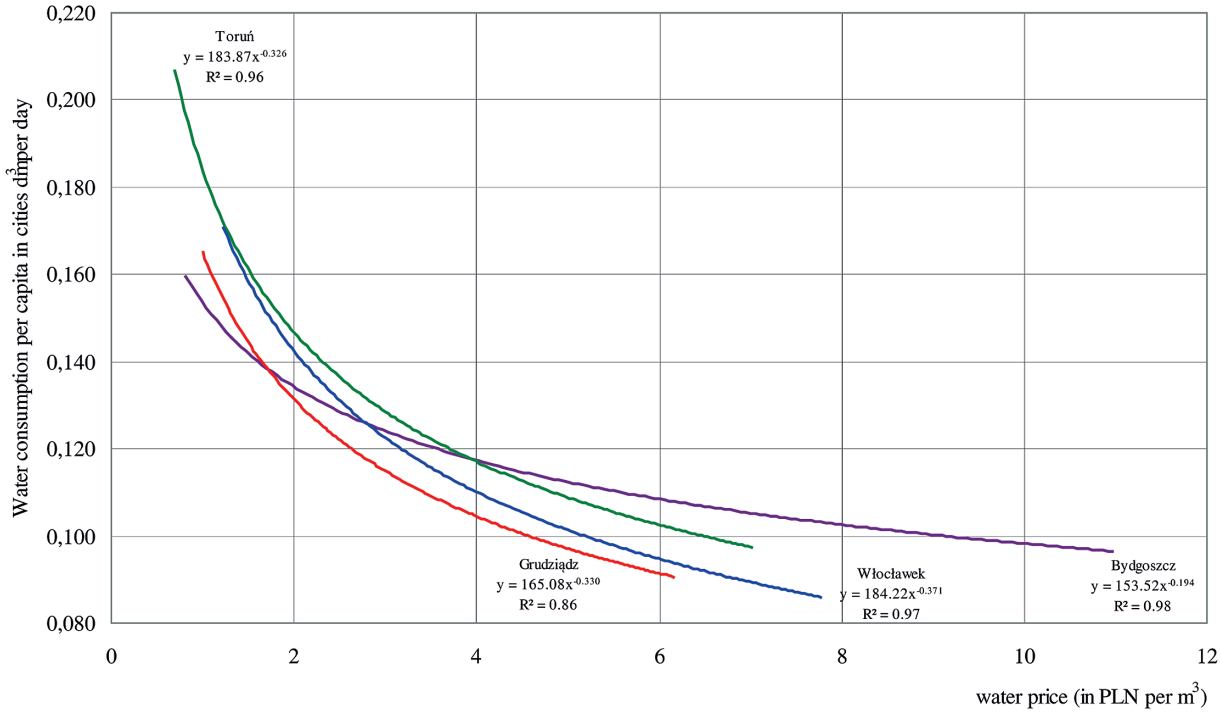


**Fig. 4.** Dependence between the water price and its consumption in the cities defined with the 1995-2012 data

*Source:* Authors' own research

Despite the effect of the change in the fees for water supply and sewage services on the unitary water consumption, they seem to be justified and logical. Despite the fact that they have been significant (Fig. 4), it does not usually allow for a precise determination to what extent the increase in the payments by a specific amount can decrease water consumption. Usually it is accounted for by a low flexibility of the water consumption price. Interestingly, for example, the historic data on the connection between water consumption and related payments in Poland are not homogenous due to a gradual process of price realignment in market economy introduced after 1990 (Flörke, Alcamo, 2004). Besides, it is often the case that the fee for the water used is provided as part of the collective bill, together with other payments connected with the operation of household, e.g., heating, gas, waste removal, etc. In such a situation the reaction of consumers to the increase in the water supply and sewage payments can occur with much delay, especially if the amount of payments changes each year by a relatively little amount. As a rule the households enjoying access to a water pipe but discharging sewage to the holding tank later emptied by septic tankers use less water than those which enjoy access to the municipal sewage system (Pawełek, Bergel, 1999). In the first case a higher unitary cost of sewage from the premises, a clear separation of the costs of the operation of the immovable property and general difficulties connected with individual collection of sewage make the owners more willing to turn to rational water management.

As for Bydgoszcz, the strongest dependence between the water price and its unitary consumption has been observed also in a short-term perspective. Periodically, the increase in the amount of payments was very dynamic here and regular for a few suc-

cessive years, which triggered dissatisfaction of the public, common and publicized in the media. Interestingly, the unitary water consumption index in Bydgoszcz and Toruń in 2012 was almost identical (approximately 0.09 $m^3$), although the prices of water supply in Bydgoszcz were that year as much as 21% higher than in Toruń. As for Grudziądz, the water payments in 2012 were 14% lower than in Włocławek. In both cities however, the average resident used a similar amount of water (0.08 $m^3$). As it seems, the socioeconomic factor which, at present, shows the strongest impact on water consumption in households is no longer so much the water price but the households sanitary facilities, which, in turn, directly comes from the living standards of the population in respective cities.

### 3.3. Sanitary facilities standard in households

Water supply companies are obliged to supply drinking water. Direct consumption including meal preparation, however, accounts on average for only 3% of the water used per household. The most water-consuming activities include flushing the toilet (about 30% of the total water consumption), taking a bath (about 25%), laundry (about 15%) and dish-washing (about 10%). Therefore almost 70% of water is used in the bathroom. After 1990, especially over the last decade, Poland recorded a considerable improvement in the sanitary facilities' standards in households. For example, in 2005 in the Kujawsko-Pomorskie Voivodeship 77.1 % of households were equipped with a washing machine and only 2.9% with a dishwasher. Over the successive five years the indicators increased to 87.8% and 10.5% respectively. Modern household appliances become more common, which was due to the decrease of their prices. For example the average price of the automatic washing machine in the Kujawsko-Pomorskie Voivodeship in 2009 was almost 20% lower, compared with the year 2000. Considering Polish conditions, the living standard of city population has been still much higher than in rural areas, which results from higher income generated by city residents. As for the residential units analyzed, the improved household sanitary facilities condition must have been even more essential than at the scale of the province. Due to lack of detailed data from particular cities, it is possible to present this problem only in a general manner.

The global trend in the design and manufacture of household sanitary facilities is aiming at a regular decrease in water consumption. A single dish-washing made by the dishwasher in the 1980s used 0.100 to 0.175 $m^3$ of water, while hand-dish-washing of the same amount of dishes required about 0.080 $m^3$. For comparison, water consumption by a modern dish-washer available on the Polish market (calculated as the average water consumption by 363 models purchasable in the country in January 2014) was only 0.011 $m^3$. A typical automatic washing-machine with the load of 5 kg in households in Poland in mid 1980s used more than 0.100 $m^3$ per washing, while the analysis of water consumption including 67 most popular washing-machine models available for purchase in Poland in January 2014 shows that today the value of that index is more than a half lower with an average of 0.043 $m^3$ per washing cycle. The capacity of the flushing toilet tanks used in the past reached even 0.015 $m^3$; which represents the amount of water flowing out with a single toilet flushing, irrespective of the needs. Today's toilet bowls allow for saving even 50% of water indispensable for flushing due to a decrease in the size of the tank to 0.006 or 0.009 $m^3$. Further savings can be made when applying double-function flushing buttons with a large (0.006 or 0.009 $m^3$) or low amount of water (0.003 or 0.0045 $m^3$, respectively). Bath, on the other hand, can be taken in a bathtub with a typical capacity from 0.100 to 0.200 $m^3$ however, at the moment, one uses shower for that purpose much more frequently, thus reducing water consumption by about 50%. Considerable savings can be possible also with an adequate selection of fittings. The water flow aerators in lavatory-taps are decreasing water consumption by 40%, maintaining the same washing effectiveness. Also installing the shower-head water-flow controllers is another example from the long list of technical solutions implemented to aid a significant decrease in water consumption in everyday household activities.

## 4. Use of water supply and sewage infrastructure against to decreasing water consumption

Over the last 100 years, following the spatial expansion of cities and an growth in population, there was an increase in the amount of water collected for municipal purposes and the distribution network also spread extensively. water supply and sewage networks, in terms of quantity, was still developing despite the depopulation of cities which begun at the turn of the century (Fig. 5).

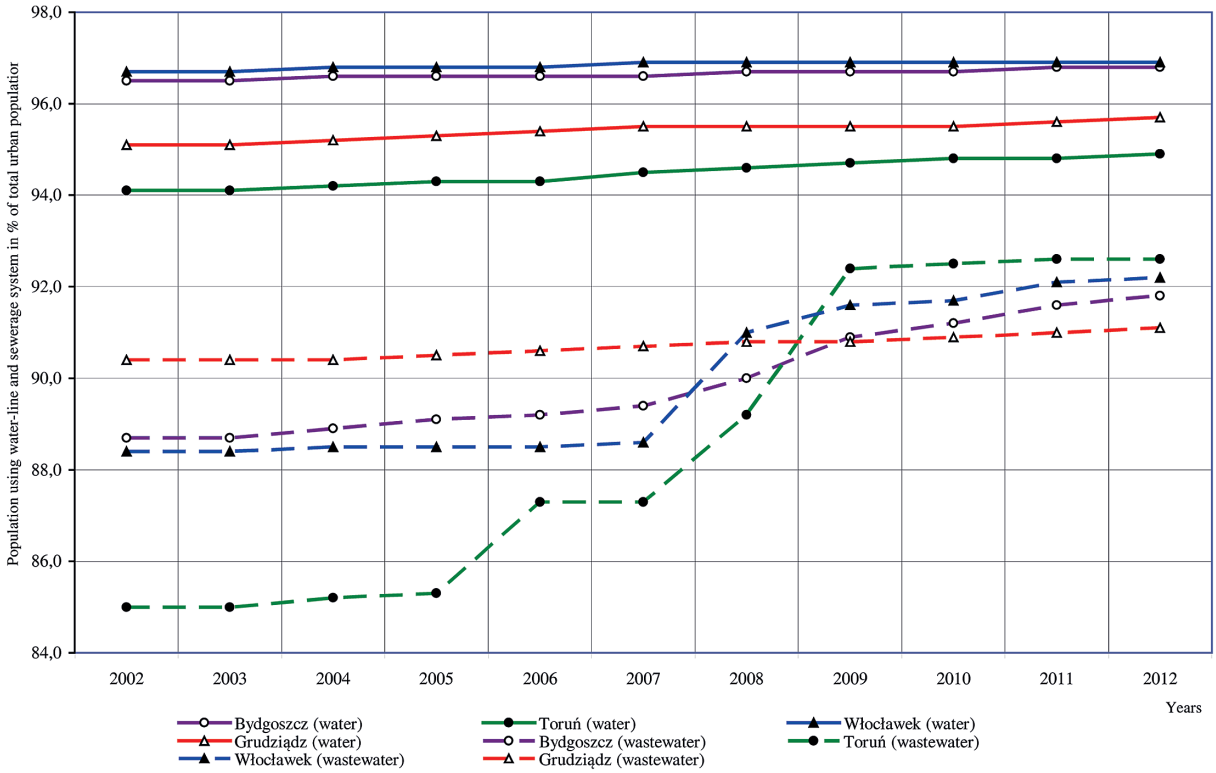


**Fig. 5.** Percentage of the population having access to the water supply and sewage infrastructure in the subject cities over 2002-2012

*Source:* Authors' own research

The development quality indicator is the attempt at the centralized water supply and sewage services system which would cover possibly the largest group of individual water consumers in the cities mentioned (Fig. 6). In 2012 the access to the water pipe was available to 94.4% of the residents of Toruń, 95.7% in Grudziądz, and almost 97% of Włocławek and Bydgoszcz, while the sewage system was used by 91.1 % of Grudziądz residents to 92.6% of Toruń residents. While planning further investments, especially those aimed at a further extension of the water supply network, one should consider the predicted future depopulation progress of cities. The condition of the development of water supply and sewage infrastructure expressed with, e.g., the total length of pipes, their capacity, the number of connections, etc., should be adequate to the needs not only existing today but also those foreseen in the future. A decreasing water consumption in households due to, on the one hand, a decrease in the household number, and on the other hand, to an improved household sanitary appliances standard, is a reason of serious problems in the operation of city water-sewage systems and the companies managing such systems.

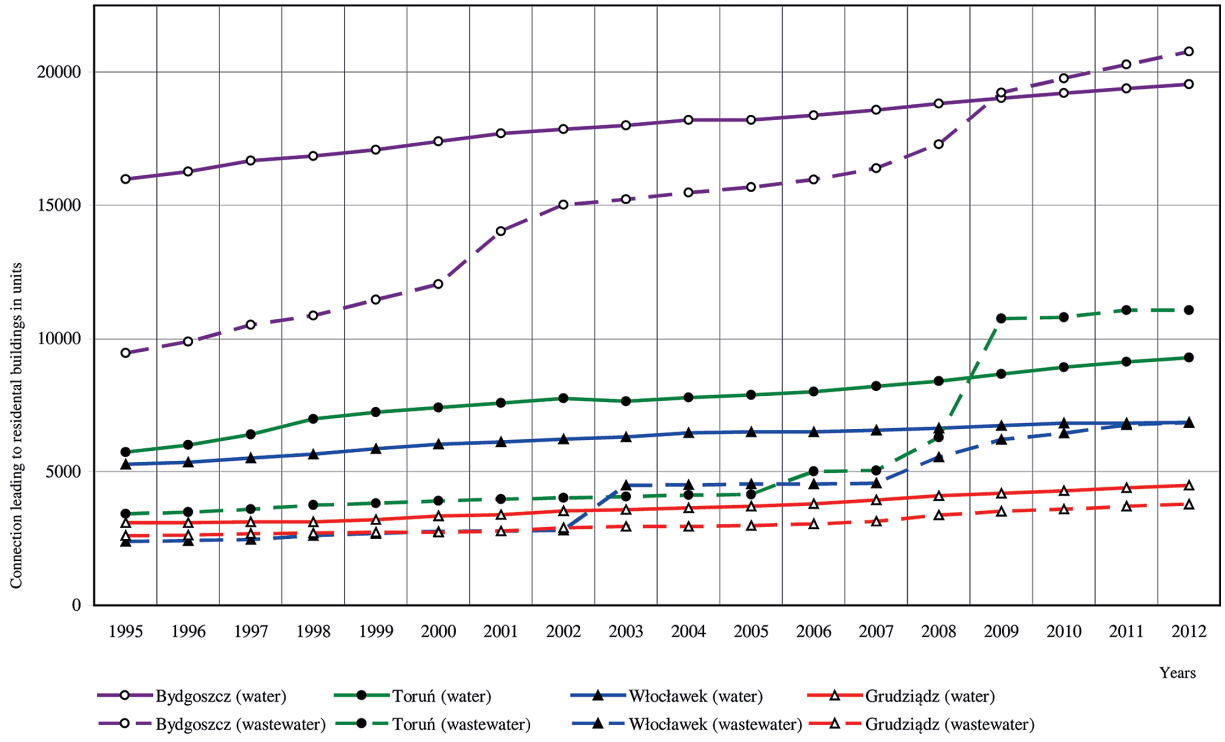


**Fig. 6.** Number of water supply and sewage connections present in subject cities in period between 1995-2012

*Source:* Authors' own research

First of all the municipal water supply and sewage infrastructure was made mostly before 1990, and so it was designed for a much greater load than it is today, at the time when the water requirements of the city were always higher than the technical water supply potential. At present it seems to be oversized in many cases. In water distribution systems it is seen from a lower water flow rate and, thus, its longer retention time, especially in magistral pipelines. With that in mind, with excessively high cross-sections of water supply pipelines, there is a real threat of secondary pollution, diminishing the effects of the, most often costly, water treatment, and thus a threat to consumer's health. As for sanitary sewage network, an inadequate amount of sewage against the pipe parameters can make the sewage remain in the pipeline and start decaying, causing a much greater burden for sewage treatment plants. Eliminating unfavorable effects of those processes involves increasing the frequency of intensive network rinsing, which, at the same time, significantly increases the operation costs related to keeping the network in a proper technical condition. The forecasts made over the recent years, showing household water consumption becoming stable, turned out to be false. In the situation when one still does not know the lower limit of the individual water consumption, there is a higher risk that the new-emerging facilities or network sections will not be able to operate with the assumed efficiency, which, besides unjustifiable additional costs, will increase also the operation costs.

## 5. Conclusions

Over the last dozen years, household water supply conditions in Polish cities have improved considerably. Many large investments were made, water intake stations were modernized, and state-of-the-art sewage treatment plants using high performance purification methods were established. Thousands of kilometers of new municipal sections of water supply and sewage networks were built, with the use of materials with a much higher, than before,

resistance to damage during operation. As a result the quality of water supplied to households has increased, as well as the quality of water in Polish rivers, collectors of treated sewage. The share of the residents having access to the water pipe and sewage system has risen considerably. All those actions were made possible due to the financial support from external sources, e.g., the European structural funds, preferential credits granted by domestic and foreign banks, and from other sources (Piasecki, 2013). However, a significant part of investment costs, between 30-50%, became a burden for city residents themselves, due to regular increase in water supply and sewage services payments.

Cities in Poland observe a further decrease in household water consumption, which goes back to the time directly after 1990, with a representative example of the four cities in the Kujawsko-Pomorskie Voivodeship, which refers to both the total water volume used by households as well as the average daily water consumption per resident. The most essential factors affecting the amount of water consumed by city residents at present and in the next few years must be the depopulation in cities and more and more rational water management per household. In such conditions there is a concern that the deteriorating financial situation of water supply and sewage companies, which results from an increase in overhead cost, related to the maintenance and operation of water supply and sanitary networks, will make the companies aim at compensating for lower profits from water sale by increasing the payments for services and introducing new payments. This, in turn, can result in a further decrease in individual water consumption; although, according to European standards, it is close to the rationally assumed minimum.

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