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Selected aspects of water and sewage management in Poland in the context of sustainable urban development

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Abstract. Effective water and sewage management is one of the most important enablers of sustainable urban development. In Poland, water and sewage management has been undergoing systematic transformation since the 1990s. This process intensified with Poland's accession to the European Union in 2004. The aim of the work is to analyse and evaluate water and sewage management in cities in Poland in terms of sustainable development. This was made possible by selecting seven variables from which a summative index (SI) was calculated. The analysis revealed a number of positive changes that have occurred in this field. These were mainly: a decrease in water consumption in households and industry, and an increased share of wastewater treated biologically or using enhanced nutrient removal in total wastewater. An increase in SI was found in 98% of the researched cities. The largest improvement in water and sewage management took place in cities of populations below 100,000 and little industry, and in three large cities, namely Warsaw and Szczecin.

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1. Introduction

The current global increase in urbanisation has contributed to a growing interest in this research area (Davis, 1955; Bertinelli, Black, 2004; Buhaug, Urdal, 2013; Jiang, O'Neill, 2017). Cities are considered to be collections of both positive and negative socio-economic processes (Henderson, 2010; Satterthwaite et al., 2010; Szymańska, 2007; Tibbalds, 2012, Belanche et al., 2016, Stevenson et al., 2016). At the same time, they have an extremely strong impact on the natural environment (Newman, 2006; Allen, 2009; Gaigné, et al., 2012; Leźniki, Lewandowska 2016). The environmental problems that cities around the world are facing are very complex, and often locally conditioned. Nevertheless, there are some shared directions of change in this area. This applies above all to implementing what are broadly considered sustainable development principles. One of the most important components of a city's sustainable development is a well-functioning water and sewage management. This applies above all to the good condition of water and sewage infrastructure with the widest possible access to it. It is also important that households and industry limit water consumption through the spreading of modern pro-ecological technologies. These factors directly favour the greening of a city.

Studies on urban water and sewage management focus on technological, technical, environmental and socio-economic aspects. Technological and technical issues relate to practical guidelines for engineers for constructing urban water and sewage networks (Todini, 2000; Pape, 2008; Coutts et al., 2013; Rojas-Torres et al., 2014) and the best water treatment and purification technologies (Tortajada, Nam Ong, 2016; Salgot, Folch, 2018). The environmental aspects of water and sewage management mainly relate to the quality and parameters of potable water (Ekiye, Zejiao, 2010; Wang et al., 2009; Coombes et al., 2016), and its impact on the natural environment (Haase, 2015; Herslund et al., 2018). The socio-economic aspects of water and sewage management focus on efficiency (González-Gómez, García-Rubio, 2008; Zarghami, 2010). They also relate to the development of practical tools for measuring and improving water infrastructure throughout its life cycle, including using the Life Cycle Assessment method (Lundin, Morrison, 2002; Sahely et al., 2005). It should be noted that urban water systems have primarily been designed to protect health and ensure safe and permanent access to water. The increase in climate-related phenomena that has been observed in recent years has caused water shortages in many areas. Much attention is thus being devoted to urban water saving (Martin et al., 2015; Hoekstra et al., 2016; Stavenhagen et al., 2018).

An OECD (2016) study of 48 cities around the globe indicated that the main challenges for the effective management of water resources will be: the aging or lack of infrastructure; national laws and regulations; extreme events; climate changes; water pollution; and political programmes' lack of interest in water issues. For these reasons, many countries and cities are already implementing various programmes designed to improve their water management systems (Daniell et al., 2015; Egan, Agyemang, 2019). For example, in Sweden, the "Sustainable Urban Water Management" research programme was initiated in 1999. The main project goals are: striving to achieve a non-toxic environment; improving health and hygiene; saving human resources; protecting natural resources; and saving financial resources (Hellström et al., 2000).

In Poland, the issue of water and sewage management has for many years been dealt with selectively. The main investments focused on extending the water supply network, and then the sewerage network. In the 1980s, the ratio of the water supply system's length to that of the sewage system was 2.6:1. Sewage, was mostly discharged directly to the receiver (a river or lake) in untreated form. The period of political and economic transformation in Poland that began only at the turn of the 1990s initiated a slow evolution in environmental protection (Piasecki 2019). Poland's desire to join the European Community (later the EU) provided a further stimulus. One key criterion was the improvement of water quality and water and sewage management.

Water and sewage management has always had a very important role in cities, and it has gained additional significance as they have grown dynamically. The aim of the work is to analyse and evaluate water and sewage management in Polish cities in terms of sustainable development. It is the authors' intention to show the changes in water and sewage management since Poland's accession to the European Union (EU). The focus was therefore on the period 2004–2016. The work includes all cities that are poviat capitals, excluding the city of Wałbrzych (due to the collected data being incomplete), i.e. 65 cities. The selected group of cities should be considered representative. It represents a total of 12.6 million inhabitants, constituting 32.8% of Poland's total population, and as much as 54.5% of the total urban population.

The work assumes the hypothesis that positive changes occurred in water and sewage management in the examined cities. The main argument for such a hypothesis was the requirement in Poland to adapt the water and sewage infrastructure to EU requirements.

2. Methods and materials

This work uses data from the Local Data Bank of the Central Statistics Office (Bank Danych Lokalnych Głównego Urzędu Statystycznego [BDL GUS]). They were used in the attempt to develop a summative index for water and sewage management. For this purpose, seven variables were selected; their natures were that of either destimulants, stimulants or nominants of water and wastewater management (Table 1). The selected variables can be defined as indicators of a city's sustainable development (Borys, 2005), which further increases their universality. At the same time, it should be emphasized that the selected variables can be supplemented with other features of water and sewage management. However, research in this area is not the subject of this work.

The destimulants of sustainable development were assumed to be *per capita* domestic water consumption (V1) and *per capita* industrial-use water consumption (V2). This is due to the need to limit the use of fresh waters in all areas of human activity. Another destimulant is the the number of people without access to sewage systems as a proportion of total population (V3). According to the principles of sustainable development, every resident should have access to the sewage system. The last destimulant is the value of BOD5 load relative to the amount of industrial sewage (V4) discharged to the waters and ground. Increased BOD5 load indicates a deterioration in water quality and an increase in pollution.

The stimulants of sustainable development were taken as the amount of water treated either biologically or by enhanced nutrient removal as a proportion of total wastewater (V5), and treated industrial and municipal wastewater treated as a proportion of total wastewater requiring treatment (V6). The increase in the value of these indices indicates the spread of waste water treatment technologies, and, thus, reduced pressure on the natural environment.

The variable of ratio of sewerage network length to water supply network length (V7) was determined as a nominant. The optimal ratio these lengths is one-to-one. When the two networks are similar, the discharge and pollution level of sewage can both be easily controlled.

Subsequently, the selected variables were transformed using the Zero Unitarisation Method in order to obtain a uniform structure of analysed variables. Then an attempt was made to calculate the

Table 1. Selected variables of water and sewage management

No.	Selected characteristics of water and sewage management	Variable
V1	Domestic water consumption (m^3) per water supply network user	D
V2	Residents without access to sewage system as a proportion of total population (%)	D
V3	*Per capita* industrial water consumption (dam^3)	D
V4	BOD5 load relative to amount of industrial wastewater discharged ($kg/yr/dam^3$)	D
V5	Wastewater treated biologically or with enhanced nutrient removal, as a percentage of total wastewater	S
V6	Treated industrial and municipal sewage as a percentage of wastewater requiring treatment	S
V7	Length of sewerage network relative to length of water supply network	N

Explanations: D – destimulant, S – stimulant, N – nominant

Source: own study based on CSO BDL data summative index (SI) of water and sewage management based on the seven variables. This was done using a method of linear arrangement of objects – the Perkal index:

$$W_i = \frac{\sum_{j=1}^{n} t_{ij}}{m}$$

where

t_{ij} – the standardised value of observation for the *i*-th case and *j*-th variable,

m – number of variables in the analysis.

The chosen method provided a summative index of water and sewage management ranging from 0 to 1.

3. Results and discussion

Water consumption is a good indicator of changes made as part of the greening of human behaviour. Therefore, raising residents' environmental awareness may also reduce water consumption. The economic factor is another strong stimulus in this respect, and is expressed in price per m^3 of water (Shaban, Sharma, 2007; Olmstead, Stavins, 2009; Harlan, et al., 2009). The importance of the two factors changes with increased societal wealth. In Poland, because income is still relatively low, the economic factor prevails. However, in the highly developed countries of Western Europe (whose societies are wealthier), the greening of human behaviour prevails (Rachock, 2003; Lewandowska, 2018).

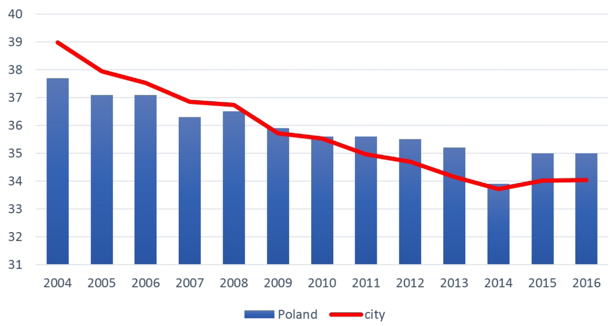

Fig. 1. Domestic water consumption (m^3) per water supply network user
Source: own study based on LDB CSO data

In the study period, there was a downward trend in water consumption. The average annual water consumption in households per water supply network user decreased from 38.9 m^3 to 34.1 m^3 in cities. Since 2013, the V1 index has stabilised somewhat at around 34 m^3. Slight increases or decreases in subsequent years can be explained variation in meteorological conditions (cool wet years, or warm dry years). At the same time, water consumption per user has increased in rural areas from 31.9 m^3 to 33.4 m^3 (Fig. 1).

The downward trend in water consumption by urban households in Poland is confirmed by numerous studies (Heidrich and Jędrzejkiewicz, 2007; Gorączko and Pasela, 2015; Piasecki et al., 2018). Many factors influenced the drop in water consumption. The most important include:

- a change in the method of calculating fees for used water – the introduction of water meters,
- the increase in water prices,
- the spread of water-efficient household appliances (washing machines, dishwashers),
- the installation of water-efficient sanitary installations and bathroom fittings,
- a drop in urban populations.

The highest V1 values were observed in the largest cities, including Warsaw and Kraków, at 51.7 m^3 and 47.4 m^3, respectively (Fig. 2). The lowest water consumption was recorded in Chełm (27.8 m^3) Łomża and Rybnik (28.2 m^3) and Suwałki (28.9 m^3).

An important stage in the development of water and sewage management in cities is to provide people with access to the sewage system (V2), while at the same time attaining a proper ratio between the lengths of the sewerage and water supply systems (V7).The two networks being similar in length allows full control over the distribution of drinking water and the discharge of waste. In many cities around the world, operations are underway to improve the quality of water and sewage infrastructure. This is to intended to make water management more efficient. The modern solutions being introduced allow costs to be reduced while reducing environmental pressure (Wang et al., 2017; Batista, 2018; Wang et al., 2018).

There has been a significant decrease in urban *per capita* industrial water consumption. The average value of variable V3 in the analysed cities decreased from 453 m^3 in 2004 to 422 m^3 in 2016. The reasons can be found in the socio-economic transformation of the country at the turn of the 1990s. It forced the closure of many unprofitable factories. These also often happened to be plants with high water consumption (Hotloś, 2010). Poland's accession to the EU also forced industry to implement many pro-ecological solutions. Industrial plants were obliged, among other things, to implement ISO 14001 standards in environmental management. These standards define basic environmental objectives, including reducing the consumption of mains water and the production of wastewater. The cities with by far the highest values of this index were Konin and Ostrołęka. These cities host two of Poland's largest coal-fired power plants. They use very large quantities of water for cooling, replenishing losses in boiler and heating circuits, and in de-slagging and ash removal (Dominiak, 2014). As a result, variable V3 is many times higher in these cities than average (Konin – 18,010 m^3 and Ostrołęka – 9,640 m^3). It should be emphasised that in 82% of the discussed cities, the value of V3 has decreased.

Another important issue in the context of sustainable urban development is wastewater management, including the amount of pollution discharged into waters. In 2004–2017, the volume of BOD5 load in industrial wastewater discharge in Poland decreased by 29% ($kg^{-1} \cdot r^{-1} \cdot dam^{-3}$). In cities the decrease was much smaller, at only 3%. In addition, the study period contained years in which BOD5 load increased (2008–2010 and 2013–2014).

Ensuring the highest level of wastewater treatment is one of the main priorities for the greening of wastewater management in modern cities. According to Art. 5 Para. 2 of Directive 91/271/EEC, Poland committed to providing wastewater treatment with enhanced nutrient removal in agglomerations of above 10,000 population equivalent. In 2016, in all cities surveyed, approximately 99.9% of wastewater was treated to this standard. In 2004, this figure was significantly lower, at 92.7%.

In the years 2004–2016, there was an upward trend in the proportion of treated municipal and industrial wastewater among total wastewater requiring treatment (V6). Only 17% of cities saw the V6 variable decrease, which included Zabrze, Olsztyn and Bytom. The main factor that caused V6 values to drop in these cities was an increase in the amount of untreated industrial wastewater.

The value of the summative water and sewage management index (SI) for the studied group of cities increased by 11.1% in the years 2004–2016. This result confirms the initial hypothesis about the

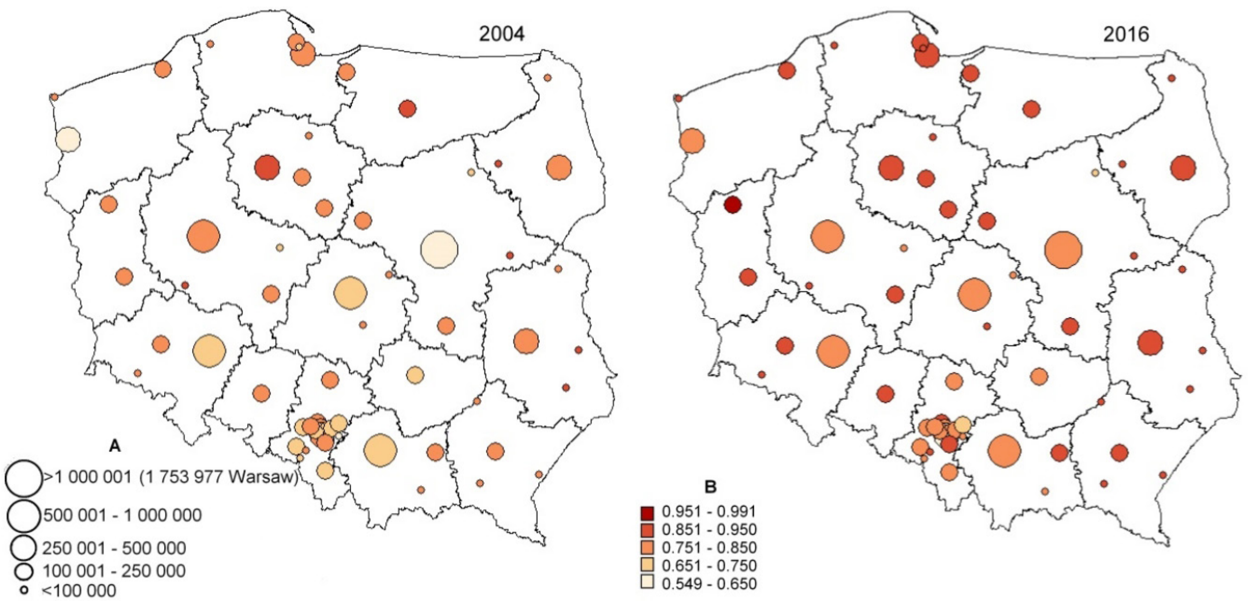

Fig. 2. Summative index of water and sewage management
Source: own study based on LDB CSO data

general improvement in water and sewage management in cities. In 2004, the highest SI values were observed in Bydgoszcz, Leszno, Zamość, Łomża, Siedlce and Olsztyn (Fig. 2). The lowest values occurred in Szczecin, Mysłowice, Jaworzno and Warsaw. In 2016, the highest SI index values were recorded in Świętochłowice, Gorzów Wielkopolski, Chełm, Łomża and Żory, while the lowest were found in Katowice, Ostrołęka, Dąbrowa Górnicza, Jaworzno, Konin and Sosnowiec (Fig. 2). The highest values of this index occurred mainly in cities with a limited number of industrial plants and high population density. The lowest index values occurred in cities with a heavily developed industry. This factor significantly lowered SI index values.

The value of the SI index was found to have increases in all cities except Katowice. The index value decreased in Katowice despite positive changes in all the component variables. However, these changes were far smaller than the corresponding transformations going on in other cities. Therefore, the final SI value for Katowice was negative.

In 2004–2016, the highest increases in the SI index were found in Szczecin (50%), Sopot (37%), Mysłowice (36%), Warsaw (29%) and Jaworzno (26%). The scale of the improvement in the index should be attributed to the major investments made in these cities. In addition, these cities are relatively small (fewer than 100,000 inhabitants, except for Szczecin and Warsaw), which means that the positive effect of the investment may have been proportionally higher than in larger cities. In Warsaw and Szczecin, the value of the WS index in 2004 was among the lowest in the researched cities. There were particularly low values in the V5 variable (Warsaw: V5=0.33, Szczecin: V5=0.0), and in V6 (Warsaw: V6=0.22, Szczecin: V6=0.07). The intensive expansion and modernisation of the sewage system and wastewater treatment plants allowed both variables to show clear improvements. Treated industrial and municipal sewage as a proportion of total sewage requiring treatment (V6) increased from 51.4% to 99.9% in Warsaw, and from 37.7% to 95.9% in Szczecin. At the same time, the standard of wastewater treatment was raised. Currently, both cities treat all sewage biologically with enhanced nutrient removal (V5). In 2004, only 3.0% of sewage was treated in this way in Szczecin, and 48.9% in Warsaw. The investments carried out resulted in V5 and V6 values approaching 1.0 in 2016.

Positive changes in urban water and sewage management in Poland have resulted from, among others, the modernisation of water and sewage infrastructure. After 2004, many projects co-financed by EU funds were implemented in Polish towns and cities. Some examples include: Poznań – the modernisation of municipal water management systems, including sewage infrastructure, the rainwater drainage system and sewage treatment plants; Radom – the modernisation and extension of water and sewage management within the agglomeration; Jaworzno – the implementation of a two-phase investment programme for potable water supply and sewage disposal; and Żory – the construction of a sewerage and rainwater drainage system, the reconstruction of the water supply network, the expansion and reconstruction of a sewage treatment plant, and the construction of a water treatment station.

The changes in urban water and sewage management identified in the work were in most cases positive. The main factors of change include new pro-ecological legal regulations, the modernisation and upgrading of industry and an increase in citizens' environmental awareness. However, Poland's accession to the EU should be considered the primary factor of change. In the Treaty of Accession, Poland undertook to implement EU law. In the field of water and sewage management this mainly concerned the Directive Water Framework (DWF) 2000/60/EC and Directive 91/271/EEC. The DWF had already been implemented in 2001 due to amendments to the Water Law Act (Regulation, 2001) and the Environmental Protection Law Act (Regulation, 2001b). The instrument for implementing the Directive is the National Programme for Municipal Waste Water Treatment (NPMWWT). The main goal of the NPMWWT is to reduce discharges of insufficiently treated wastewater. The latest NPMWWT update of 2017 indicates that all requirements of Directive 91/271/EEC were met by only 525 agglomerations of the 1,587 included in the programme. By 2021, this number is expected to rise to 1,036 agglomerations. This confirms that the issues of water and sewage management in Polish cities remain not completely resolved. Further investments in this regard are required. However, financing for these investments may be difficult to acquire. In recent years, Polish cities have carried out a lot of investments, especially infrastructural investments using EU funding. As a result, a significant portion of them is currently heavily in debt. This fact may significantly limit further investments in water and sewage infrastructure.

4. Summary

The results allow changes in water and sewage management in the analysed cities in the years 2004–2016 to be identified as positive. The research hypothesis was confirmed. The calculated increase in the summative index was 11.1%, which should be considered relatively low. However, it should also be emphasised that all investments carried out in water and sewage management are long-term. This means that their positive effects are often observed after a delay. The greatest improvement in the field of water and sewage management (and thus the highest SI index values) was found in cities with a population of less than 100,000 and underdeveloped industry.

It should be emphasised that the noticeable improvement in urban water and sewage management has not eliminated all environmental problems. The amounts of pollutants entering water and land from industrial plants are still problematic. In addition, the quality of water and sewage infrastructure in cities still requires modernisation and upgrading. Local authorities should bear in mind that well-functioning water and sewage management is crucial in ensuring sustainable urban development.

The work is not an exhaustive treatment of the issue, and in many areas only outlines this complex research problem. Therefore, further in-depth research is planned in this area.

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