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# A Comparative Analysis of Drinking Water Quality Management Systems in Poland

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***Abstract:***

***Purpose:*** *The article aims to present and discuss the results of comparative analysis of applied methods in water treatment processes, and to assess whether they belong to the group of advanced and strategic methods used in the treatment and improvement of drinking water quality.*

***Design/Approach/Methodology:*** *The theoretical part of the article discusses the state of drinking water regions of Poland in terms of its chemical, physical, and biological properties, considering the level of pollution. Next, the drinking water quality management scheme in Poland is presented from the organizational point of view, then, Poland's drinking water quality regulations, both national and EU, have been characterized, as well as a few legal norms and programs supporting the ecological campaign in Poland "I drink tap water". In the succeeding part of the article, attention was paid to a detailed analysis of the methods used in Poland in the processes of drinking water treatment and improvement.*

***Findings:*** *Based on the comparative analysis, final conclusions have been drawn up indicating the most effective and ecologically sound methods used in water treatment processes to improve drinking water status in the regions of Poland in such a way that it not only meets legal and environmental standards but is also an essential factor in improving the quality of health, life and economic situation of a given social group.*

***Practical Implications:*** *The article brings a number of valuable information that can be the base material and reference to further research, programs and studies for local governments, practitioners and scientific specialists dealing with issues of improving the quality of drinking water, effective management of water resources, ecology or aspects of environmental protection.*

***Originality/Value:*** *The results of the comparative analysis and theoretical considerations in this article complement the current research in the field of drinking water quality management, and may become a valuable resource of knowledge and a set of specimens that can be useful in developing dissertations in the field of management, environment and ecology.*

***Keywords:*** *Drinking water, quality, management systems, management, water treatment processes.*

***JEL code:*** *Q25, Q53.*

***Paper type:*** *Research article.*

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## 1. Introduction

A crucial task for the public authorities is to ensure adequate quality of water planned for human consumption, which is fulfilled through the various ways of maintaining its value and improve it up to the expected standards. All actions taken towards the guaranteeing the quality of water include monitoring and control of water intakes, their conditions, as well as establishing their protection zones. Underground and surface intakes are the sources of water supplies for citizens for their consumption, and therefore, they must meet specific requirements. Among them, one should include the excellent quality of groundwater which does not require treatment, or such procedure is required in a minor process and, as well, the treatment of surface water which due to its quality requires respective methods of purification (Nowacka *et al.*, 2015).

The quality of groundwater is conditioned by the amount and type of impurities entering the soil or contaminants migrating from the surface to the aquifer feed intake, whereas, the quality of surface water is conditioned by the quantity and type of impurities coming from the ground surface and entering the water intake. The contaminants in groundwater may appear after years and thus, such essential it is to maintain the regular control of water intakes zones to guarantee their safety and preservation. Furthermore, the public authorities should regularly monitor the standards of water supply chains to ensure an appropriate state of drinking water as a final good.

## 2. Materials and Methods

This article uses a comparative analysis of various drinking water treatment systems in selected Polish cities based on several acquired materials, reports and literature resources. The collection of data and information included 22 Polish cities with a population of more than 150 000 people and was completed between 2017 and 2018. The authors of the paper gathered the statistical data, official municipal documents obtained from the Municipal Water Supply units, Water Utility Companies within the country and the Sewerage Companies' websites, statutes and regulations, both Polish and EU, as well as the information from the campaign materials promoting tap water consumption throughout the country. The data and information were obtained through the telephone interviews and by studying the available website reports and news. The collected data was summarized in tables, and then the results of the comparative analysis were discussed to draw, at the final stage, the appropriate conclusions.

## 3. Theoretical Background

### 3.1 Domestic and EU Legal Regulations on Water Quality in Poland

The basic law act regulating the principles of preserving and improving water quality in Poland is the Act of July 20, 2017 - Water Law which includes all assumptions of the Council Directive 91/271 / EEC of 21 May 1991 concerning urban wastewater treatment, as well as the Council Directive 91/676 / EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources. The general aim of the Act is to normalize the management of water supplies in Poland in terms of sustainable development regarding the protection and conservation of water intakes, water resources and their management (Cano-Rocabayera, 2019).

Additionally, the above acts are also supported by the norms counted in Directive 2000/60 / EC of the European Parliament and of the Council of 23 October 2000 establishing a Community framework action in the field of water policy which regards water as a heritage to be protected and not as the product to be treated in a commercial way. Such an approach to water is the result of the European citizens' initiative which in 2014 started a campaign called "Right2Water" during which a motto "Water and Sanitation are a human right! Water is a public good not a commodity!" (EC, 2014). Similarly, in Poland a campaign "I drink tap water" has been introduced by two young people M. Kożurno and S. Boniecki who propagate a trend to drink tap water in all cities through social media, national and local newspapers and television channels. The action has been widely spread and become a trend for the future which corresponds to EU policy.

The foremost objective of all members of European Union should be implementing the strategies to systematically improve the quality of surface waters in terms of ecological aspects, protection of groundwater against the pollution, and avoiding the deterioration of freshwater quality, as well as to taking actions towards the sustainable management of water resources. The Water Law in Poland, therefore, puts the emphasis on water resources management which aim is to meet the needs of the population and economy, i.e.:

- provide adequate water quality and quantity for the population,
- protect the country against floods and drought,
- protect water resources against pollution and improper or excessive use,
- maintain or improve the water and water-dependent ecosystems,
- provide water for agriculture and industry,
- create conditions for energy, transport, and fishing use,
- meet the needs of tourism, sport, and recreation.

The regulations included in the Directive of the Council of the European Union 98/83 / EC specify the parameters of the permitted concentration of harmful substances, color, turbidity, the total number of bacteria, the total organic carbon content, taste and odor. Polish drinking water control stations monitor the level of organic and mineral substances, level of contamination to meet appropriate standards of cleanliness and suitability for consumption. According to The Commission Synthesis Report on the Quality of Drinking Water in the EU examining the

Member States' reports for the period 2008-2010 under Directive 98/83/EC (EC, 2014), the general overview of water quality in EU is perfect and in case of large water suppliers it can be noticed that compliance rates for microbiological and chemical parameters estimate between 99% and 100%. Other States' rates are lower than 99%, and in these cases the action to improve the drinking water qualities should be incorporated. As stated by the Drinking Water Directive (98/83/EC) in 2010, there are 96,388 water supplies zones in the EU (11,233 large water supplies and 85,559 small water supplies) which approximately serve 474 million people, and the drinking water quality varies due to certain factors, such as:

***Large supplies:***

- microbiological parameters – 23 EU members reached full compliance of 99-100%. Lower rates were noticed in Bulgaria, Cyprus, Hungary and Latvia,
- chemical parameters – all countries in EU had compliance rates above 90% except for Hungary (parameter arsenic), Ireland (parameter trihalomethane) and Lithuania (parameter fluoride),
- indicator parameters – maximum performance rates (99-100%) was achieved by seven countries, ten accomplished 95%, next ten between 90% and 95%, whereas parameters rates below 90% were reported in Denmark (Coliform bacteria), Hungary (ammonium), Latvia (sulphate) and Malta (chloride and sodium).

***Small supplies:***

- microbiological parameters – in Estonia, Malta and Sweden rates were over 99%, rates between 95-99% were reported in 14 countries, Bulgaria, Cyprus, Italy and the United Kingdom reported rates between 90-95%, and rates below 90% were noticed in Denmark, Lithuania, Poland, Romania, Slovenia and Greece,
- chemical parameters – in this case, the compliance does not differ much from the large supplies,
- indicator parameters – performance rate in many countries was noticed to be at the level of above 95% and some significant problems that the report indicated remained due to coliform bacteria, clostridium perfringens, iron, manganese, ammonia and pH,
- Even though water quality both in Poland and in other countries of the European Union is reported to be in a very good condition, it still requires a significant focus on its improvement and preservation, and hence, the public authorities should not disregard the applicable regulations.

### 3.2 Attributes of Water in Poland and the Quality Management System

Poland is in the basins of three seas. It is primarily the Baltic Sea catchment area (99.7% of the country's territory) which is formed by two river basins of the largest rivers: the Vistula River (54% of the country) and Odra (33.9% of the country) assisted by smaller five river basins: Ücker, Jarft, Świeża, Pregles and Nemunas, as well as river basins falling directly into the Baltic (5.5% of the country). The other two catchments are the North Sea basin (0.1% of the country) and the Black Sea (0.2% of the country). Groundwater resources available for conversion in Poland are about 13.9 billion m3 per year, and currently, the use of that supply is about 20%. Those in the Vistula river basin estimate to 22.2 million m3 per day and 8.1 billion m3 per year. In the Odra river basin and the Western Pomeranian rivers, the amount of groundwater resources that are possible to be utilized is combined are about 15.9 million m3 per day, which is in total 5.83 billion m3 per year. Water resources in Poland are relatively poor, and its quality is mainly disturbed by excessive exploitation and mining drainage, or the inflow of residues of fertilizers, sewage and polluted water and uncontrolled leaks of fuels and chemicals.

Like in other European countries, in Poland water is taken from groundwater and surface waters and in case of groundwaters, it has been recorded that in smaller towns and villages the concentration of minerals and organic is increased. According to the report on the state of water quality in Poland of the Supreme Chamber of Control in Poland, there exists a problem of a not fully developed strategy of protecting the water resources and intakes, as well as preserving the waterpipes chains supplying water to the citizens. The general control, which included 12 water supply companies, 12 municipal offices and six district sanitary and epidemiological stations in years 2013-2016, concluded that the entities do not provide adequate actions to guarantee the quality of water for consumption, both at the level of its capturing process and later when it is already transported in a supply network. The problem roots in the fact that the local authorities do not pay enough attention to protecting the zones of water intakes which become contaminated by the external anthropogenic factors, they fail to comply with conditions, which result in worsening of the standards of water supply networks and water quality itself.

Moreover, there has been reported that the citizens are not entirely informed about the quality state of drinking water – as detailed by the Supreme Chamber of Control, 40% of controlled municipalities did not educate their citizens about the factual quality of water as it is required by law.

Regarding the above issues, there appears a prerequisite to analyze the systems of management of quality of water in Poland due to its chemical, physical, and biological condition and the level of impurities. According to the Minister of Health’s Regulation of 29 March 2007 there are requirements for the drinking water not to contain micro-organisms and parasites and chemicals in a health-threatening quantity. Due to that the process of water treatment in Poland assumes several stages, including filtration, iron removal, softening, demineralization, carbon filtration, disinfection, aerating and denitrification (Mirbagheri *et al*., 2016). The Ordinance of the Minister of the Environment of 27 November 2002 on the requirements to be met by surface waters used to supply the population with drinking water: 2002, No. 204, item. 1728 established three classes of surface waters intended for consumption:

- category A1 - water requiring simple physical treatment (filtration, disinfection),
- category A2 - water requiring typical physical and chemical treatment (pre-oxidation, coagulation, flocculation, decantation, filtration, final chlorination disinfection),
- category A3 - water requiring great physical and chemical treatment (oxidation, coagulation, flocculation, decantation, filtration, activated charcoal adsorption, ozonation or final chlorination).

For the water control stations, the most important thing is to assess the presence of chemical impurities as well as physical characteristics, for instance, water's color and clearance, or biological features like presence of fecal and pathogenic bacteria. Since 2008, due to regulations included in Water Framework Directive, there five classes for the water quality according to its ecological status:

- first-class quality - excellent ecological status or maximum environmental potential (the biological quality of the water reaches values corresponding to values in undistorted or slightly disturbed conditions, and physicochemical parameters fall within the range corresponding to the undisturbed conditions),
- second class quality – functional ecological status (the biological quality of the water reaches values indicating anthropogenic impact, i.e. just minor deviations occur from undisturbed conditions, and the ecosystem functions well and does not negatively affect biological elements),
- third-class quality – moderate ecological status (average deviations from the natural biocenosis, but physicochemical components exceed the values typical of good state),
- fourth class quality – poor ecological condition or weak environmental potential (significant deviations from the natural biocenosis),
- fifth class quality – poor ecological status, reduced environmental potential (severe deviations from the natural biocenosis together with the absence of typical biocenoses = biological elements indicate bad condition).

In the five-grade classification, class I meets the requirements of the surface waters as a consumption supply for the population and corresponds to category A1, class II and III correspond to category A2, whereas, class IV matches the regulations of category A3. Class V does not meet the requirements for surface waters dedicated to the population as the drinking water. The quality of the water is subjected to testing with a few indicators separately analyzed. Evaluation of parameters is the result of research based on multidimensional methods, which allows studying multivariate indicators of parameters. Individual sanitary and epidemiological stations, water supply agencies and local government bodies need to implement appropriate water management systems that require these days to be supported by modern non-standard water treatment technologies. The innovative technologies together with standard chemical methods may improve sensory and health properties of drinking water provided by water supply systems. Water as the environment's resource needs to be managed sustainably in terms of economic and ecological-social development. Sustainable development means, among other things, the process of using natural resources in a planned and organized way which enables to meet the needs of the present generation without prejudice to the needs of future generations. The water management system in Poland is based generally on information which includes observation of:

- hydrographic networks and measuring stations,
- catchment areas, river basins and water regions,
- groundwater resources, major groundwater reservoirs, stationary water networks,
- the quantity and quality of water and the amount,
- pollutants' sources and physiognomies,
- the aquatic environment and floodplains biological status,
- fishing grounds and their water usefulness,
- characteristics of water use,
- water law permits and/or licenses,
- quantities and types of harmful substances to the water environment,
- protected zones and flood risk areas,
- waterworks and water companies,
- as well as on planning based on program water-environment led by the President of the National Water Management Board (NWMB) and directors of regional boards.

The main task of the NWMB is to cooperate with the Minister of Environment and 7 Regional Water Management Boards (RWMB) which are obliged to cover one or more of 21 water regions in Poland located within ten river basin districts. Water monitoring data is directed by the Chief of Inspector for Environmental Protection (CIEP) who additionally conducts the status assessment. Voivodship inspectors for environmental protection deliver adequate information and analysis. Under supervision of the Minister of Environment and the NWMB, individual regions have implemented various technological system solutions supporting the treatment of drinking water, which belong to the drinking water quality management systems. These are worth analyzing in terms of their effectiveness and performance to deduce which bring the best water treatment results.

## 4. Results and Discussion

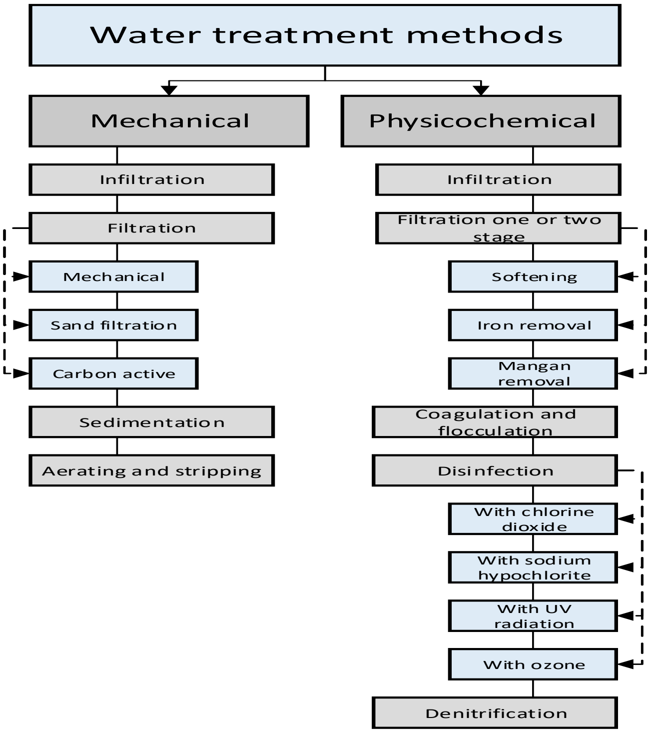
### 4.1 The Applied Water Treatment Methods in Poland and their Efficacy

The water treatment process consists of adjusting its properties and composition to the requirements, that result from its intended use. Its primary purpose is to remove pathogenic organisms from the water and to give it the proper taste attributes (Piekutin, 2012). Whereas water purification is the process conducted to restore its quality. It is also the removal process of contaminants from raw water to produce drinking water or water that can be returned to the environment without affecting its condition (Kowal and Świderska-Bróż, 2009). The water treatment methods are divided into two groups: mechanical and physicochemical (Figure 1).

In the earlier part of this article, several water-treatment methods have been already listed, such as filtration, iron removal, softening, demineralization, carbon filtration, disinfection, aerating and denitrification. In part below, these water treatment methods will be described in a more detailed way, as well as some additional techniques, used in Polish municipal water and sewerage companies.

*Infiltration* is a process in which physical, chemical, and biological phenomena take place. Infiltration can be either natural or artificial (Kowal, 1999). *Filtration* consists in removing a hardly falling slurry, which usually takes the form of quartz sand of different thicknesses. There could also be a sand and carbon active filtration (Ćwikła and Konieczny, 2009; 2011).

***Figure 1.*** *Water treatment methods*




**Source:** *Own elaboration*.

*Carbon (C) filtration* uses active carbon, which is a specially prepared substance (charcoal, anthracite, semi-coke, lignite or coal), characterized by high porosity. A large surface of pores causes a high absorption of organic substances present in the water. Moreover, highly compressed carbon blocks in water filters remove particles up to 0.5 microns, including *the Giardia cysts* or *cryptosporidium*, turbidity, and pollen (Kaleta *et al*., 2017; Kovalova *et al*., 2013; TylkoWoda.pl, 2017).

*Sedimentation* consists of removing tiny and easily falling slurries with horizontal, vertical, and radial settling tanks, bars and sieves (Seneviratne, 2018; Ostrovsky *et al*., 2014). *Aerating and stripping* it consists in removing odors by aeration of water under atmospheric pressure. The effectiveness of this method is influenced by many factors such as temperature, the size of air bubbles, surfactants, mixing, the depth of the active chamber, diffusion process and diffusers' distribution and diffusion capacity (Weber, 2008). *Softening* consists of removing the hardness of water caused by the presence of calcium and magnesium ions (Skipton and Dvorak, 2014).

*Manganese (Mn) removal* the first stage in this process is to raise the water pH, because the higher alkaline reaction, the easier manganese removal is. However, most often, this process is included in one-stage or two-stage filtration (Bestova *et al*., 2011). *Iron (Fe) removal* involves the divalent iron oxidation and filtration of precipitated $Fe(OH)_3$. Water deferrization can be carried out by aerating and filtration on quartz and catalytic layers or without aerating on specialized zeolitic layers rinsed with brine. Very often, iron and manganese removal and softening are carried out together and are described as one-stage or two-stage filtration (Pisarski, 2018).

*Coagulation and flocculation* consist of adding coagulants, such as $Al_2(SO_4)_3$ (aluminum sulfate), into turbid water, which causes flocculation. Then precipitated fine flocks transforms into large flocks $Al(OH)_3$ (aluminum hydroxide). The primary purpose of coagulation is water's turbidity removal and its color reduction (Nowacka *et al*., 2016). The water's turbidity is caused by the presence of clays, colloidal silica, or compounds of colloidal calcium (Smith, 1920; Dentel, 2009). *Disinfection's* main task is to remove the microorganisms present in the water and to secure the good quality of sanitary water in the water supply. The purpose of disinfection is to destroy the microorganisms present in the water after the previous processes of its purification and to protect the water from the further growth of living organisms. Disinfection uses chlorine dioxide ($ClO_2$), sodium hypochlorite (NaOCl), ozone ($O_3$) and UV radiation (Gromiec and Gromiec, 2013).

*Denitrification* is a process of water treatment during which inorganic nitrogen forms, such as nitrates, are reduced. Denitrification plays an essential role in nature, primarily because nitrate level is significant for water quality (Carlson and Ingraham, 1983; Spanning *et al*., 2005; Cornish Shartau *et al*., 2010; Dähnke and Thamdrup, 2013).

As can be seen from the water treatment methods listed above, there are a lot of them, whose primary purpose is to make water safe to drink. Some of these methods are characterized by high efficiency, while others provide satisfactory efficiency, in combination with the following methods only, such as water softening or demineralization. The other methods' effectiveness depends on many factors, which need to be considered, e.g. when designing a water treatment plant in which, the chosen method will be used, e.g. aerating and stripping.

### 4.2 Analysis of the Water Treatment Methods Used in Polish Cities

In Poland, water treatment processes are most often conducted in Water Treatment Plants operating in each city in Poland. The number of these stations does not depend on the size of the town but on the groundwater system and ways of obtaining water as well. To determine which water treatment methods are the most used in Poland, a comparative analysis was conducted for all cities in Poland with a population of over 150,000 citizens. The information is presented in Table 1.

***Table 1.*** *The list of selected Polish cities*

| City | Population (for 1.01.2017) | The number of Water Treatment Plants | City | Population (for 1.01.2017) | The number of Water Treatment Plants |
|---|---|---|---|---|---|
| Bytom | 169 617 | 2 | Bialystok | 296 628 | 3 |
| Bielsko-Biala | 172 030 | n/a | Katowice | 298 111 | 3 |
| Olsztyn | 172 993 | n/a | Lublin | 340 466 | 2 |
| Zabrze | 175 459 | 2 | Bydgoszcz | 353 938 | 2 |
| Gliwice | 182 156 | 1 | Szczecin | 404 878 | 6 |
| Rzeszow | 188 021 | 1 | Gdansk | 463 754 | 8 |
| Kielce | 197 704 | 2 | Poznan | 540 372 | 1 |
| Torun | 202 521 | 2 | Wroclaw | 637 683 | 2 |
| Sosnowiec | 205 873 | 4 | Łodz | 696 503 | 3 |
| Radom | 215 020 | 2 | Krakow | 765 320 | 4 |
| Czestochowa | 226 225 | 5 | Warszawa | 1 753 977 | 2 |
| Gdynia | 246 991 | 8 | | | |

**Source:** *Own elaboration.*

Carrying out such an analysis would make it possible to assess which of the water treatment methods are used by Water Utility Companies the most often, so that the water received by the citizens, would have the highest quality and meet the specified parameters. In the case of selected cities, the number of citizens exceeds 150 thousand, and one could assume that the chosen methods are the most effective and ecological. The method of analysis was to obtain information from Municipal Water Supply and Sewerage Companies' websites. In addition to data acquired from the websites of companies mentioned above, more accurate information has been acquired through telephone interviews. The only city that did not give any information about the water treatment methods was Olsztyn. Thus, the overall number of cities covered by the analysis was 22 cities with a population of over 150,000.

From the collected information, as shown in Table 2, it indicates that the aerating and stripping, sand filtration, carbon active filtration and disinfection with chlorine dioxide ($ClO_2$) are the most often used water treatment methods. Based on the acquired information, it can be concluded that the most commonly used water treatment process is a process consisting of the following steps: sand filtration, active carbon filtration (C active), aerating and stripping, disinfection with chlorine dioxide ($ClO_2$). Aerating and stripping is used in 13 cities (59%), sand and carbon active filtration and disinfection with chlorine dioxide in 12 cities (54%). And denitrification is used in one city only.

***Table 2.*** *The list of water treatment methods used in selected cities*

| City/ methods | | Filtration | | | One or two-stage filtration | | | | | | Disinfection | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Infiltration** | Mechanical | Sand filtration | C active | Softening | Mn removal | Fe removal | **Sedimentation** | **Aerating and stripping** | **Coagulation and flocculation** | with $ClO_2$ | with UV radiation | with NaOCl | with $O_3$ | **Denitrification** |
| Bytom | | X | X | X | | | | | X | X | | | X | | |
| Bielsko-Biala | | | | | | | | | | | | X | | | |
| Zabrze | | | X | | X | X | X | | X | | X | | X | | |
| Gliwice | | | | | | X | X | | X | | | X | X | | |
| Rzeszow | | X | | X | | | | X | | X | X | | X | | |
| Kielce | | | | | | | | | | | | | X | | |
| Torun | | X | X | X | | | | | | X | X | | | | |
| Sosnowiec | | | X | X | | | | | | X | X | | | | |
| Radom | | | | | | | | | X | | | | | | |
| Czestochowa | | | | | | X | X | | | | | | X | X | X |
| Gdynia | | | | | X | X | X | | X | | | X | | | |
| Bialystok | | | X | | | | | | X | | X | | | | |
| Katowice | | | X | X | | | | | X | X | X | X | | | |
| Lublin | | | | | | X | X | | | | X | | X | | |
| Bydgoszcz | X | | | X | | X | X | | X | | X | | | | |
| Szczecin | | | X | X | | X | X | X | X | X | X | | X | | |
| Gdansk | | X | X | X | X | X | X | X | X | X | X | | | | |
| Poznan | X | | X | X | | | | | X | | X | | | | |
| Wroclaw | X | | X | X | | | | | | | | | | X | |
| Lodz | | | | | | | X | | | | | | | | |
| Cracow | | | X | X | | | | | X | X | X | X | X | | |
| Warsaw | X | X | X | X | X | | | X | X | X | | | | | |

***Source:*** *Own elaboration.*

On the further places, the following methods of water treatment methods were found: one or two-stage filtration, coagulation and flocculation and disinfection with sodium hypochlorite (NaOCl). The methods are presented in Table 3.

***Table 3.*** *Use of one or two-stage filtration, coagulation and flocculation and disinfection with sodium hypochlorite methods in selected Polish cities*

| City/methods | One or two-stage filtration | | Coagulation and flocculation | Disinfection with sodium hypochlorite |
|---|---|---|---|---|
| | Mangan removal | Iron removal | | |

| | | | | |
|---|---|---|---|---|
| Bytom | | | X | X |
| Zabrze | X | X | | X |
| Gliwice | X | X | | X |
| Rzeszow | | | X | X |
| Torun | | | X | |
| Sosnowiec | | | X | |
| Katowice | | | X | |
| Kielce | | | | X |
| Czestochowa | X | X | | X |
| Gdynia | X | X | | |
| Lublin | X | X | | X |
| Bydgoszcz | X | X | | |
| Szczecin | X | X | X | X |
| Gdansk | X | X | X | |
| Lodz | | X | | |
| Cracow | | | X | X |
| Warsaw | | | X | |

***Source:*** *Own elaboration*.

Disinfection with sodium hypochlorite method is almost as often used as disinfection with chlorine dioxide method. It can be assumed then, that by examining, e.g. all cities in Poland, half of them would use disinfection with sodium hypochlorite method, and the other half - disinfection with chlorine dioxide method. Coagulation is one of the water treatment methods that proceeds through two stages. First, the stable colloid is transformed into unstable (coagulation) and then the formation of expanded agglomerates (flocculation) occurs. Based on the analysis, 36% of the surveyed cities use a one- or two-stage filtration method, which includes methods: iron removal, manganese removal and softening. However, iron and manganese removal methods are used only, but it is worth to note that Lodz uses iron removal method only.

Considering that the remaining 64% of the cities, do not use these methods, it can be assumed that the water taken from the depots or groundwater system is characterized by low iron and manganese level and is soft enough. On the other hand, to the least used water treatment methods in selected cities, shown in Table 4, we can include infiltration, mechanical filtration, softening, sedimentation, disinfection with UV radiation and with ozone and denitrification.

***Table 4.*** *The least used water treatment methods in selected Polish cities*

| **City/methods** | **Mechanical filtration** | **One or two-stage filtration -softening** | **Sedimentation** | **Disinfection with UV radiation** | **Disinfection with ozone** | **Denitrification** |
|---|---|---|---|---|---|---|
| Bytom | X | | | | | |
| Bielsko-Biala | | | | X | | |
| Zabrze | | X | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Gliwice | | | | X | | |
| Rzeszow | X | | X | | | |
| Torun | X | | | | | |
| Czestochowa | | | | | X | X |
| Gdynia | | X | | X | | |
| Katowice | | | | X | | |
| Bydgoszcz | | | | | | |
| Szczecin | | | X | | | |
| Gdansk | X | X | X | | | |
| Poznan | | | | | | |
| Wroclaw | | | | | X | |
| Cracow | | | | X | | |
| Warsaw | X | X | X | | | |

***Source:*** *Own elaboration.*

It is also worth to mention that besides the rare use of disinfection with ozone as one of the methods, ozone itself is very often used in selected cities (Table 5). Ozone is used in the process called preliminary ozonation, indirect ozonation but also is used by the disinfection and aerating. Preliminary ozonation and this is the first step in the entire water treatment process. Then, after the filtration process, the water is subjected to a process called indirect ozonation. The popularity of this method is influenced by the fact that it is one of the most effective solutions, ensuring the high quality of treated water.

Table 5 indicates that the indirect ozonation is very often used, among 22 surveyed cities, 8 of them (36%) use this process throughout the overall water treatment process, while the preliminary ozonation and aerating with ozone are used in three cities only. Besides, the use of ozone does not affect the state of the environment, which causes that this method is perceived as a sustainable water treatment method. Ozonation removes harmful substances, dyes, odors and microorganisms, and ozone itself adopts the form of pure oxygen.

***Table 5.*** *The use of ozone in selected Polish cities*

| **City/methods** | **Ozonation** | | **Disinfection with ozone** | **Aerating with ozone** |
|---|---|---|---|---|
| | preliminary | indirect | | |
| Gliwice | | X | | |
| Rzeszow | | X | | |
| Torun | X | X | | |
| Sosnowiec | X | X | | |
| Czestochowa | | | X | |
| Bialystok | X | X | | X |
| Katowice | | X | | |
| Bydgoszcz | | | | X |
| Szczecin | | | | X |
| Poznan | | X | | |
| Wroclaw | | | X | |
| Warsaw | | X | | |

***Source:*** *Own elaboration.*

It was also analyzed, which of the selected cities is characterized by the most complex water treatment process, which includes the methods mentioned above. A total of 15 water treatment methods were characterized in this article. And most of them are the stages of the whole water treatment process that is used in the selected cities (Table 6). In some cities, this process is complex, such as in Gdansk and Szczecin. In both these cities, the whole water treatment process includes 10 (Gdansk) and 9 (Szczecin) water treatment methods. Zabrze, Warsaw, and Cracow are on the next place. In Warsaw, the whole water treatment process includes the use of eight methods and in Cracow and Zabrze - seven. In turn, in cities such as Bytom, Zabrze, Rzeszow, Katowice and Bydgoszcz, only six methods are used in the whole water treatment process.

***Table 6.*** *The list of Polish cities with the most complex water treatment process*

| City /methods | | Filtration | | | One or two-stage filtration | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Infiltration | Mechanical | Sand filtration | C active | Softening | Mn removal | Fe removal | Sedimentation | Aerating and stripping | Coagulation and flocculation | with $ClO_2$ | with UV radiation | with NaOCl |
| Bytom | | X | X | X | | | | | X | X | | | X |
| Zabrze | | | X | | X | X | X | | X | | X | | X |
| Rzeszow | | X | | X | | | | X | | X | X | | X |
| Katowice | | | X | X | | | | | X | X | X | X | |
| Bydgoszcz | X | | | X | | X | X | | X | | X | | |
| Szczecin | | | X | X | | X | X | X | X | X | X | | X |
| Gdansk | | X | X | X | X | X | X | X | X | X | X | | |
| Cracow | | | X | X | | | | | X | X | X | X | X |
| Warsaw | X | X | X | X | X | | | X | X | X | | | |

***Source:*** *Own elaboration.*

Less complex water treatment processes occur in cities: Gliwice, Torun, Czestochowa, Gdynia, and Poznan, where five methods are used in the water treatment process. But in Gliwice, instead of mechanical, sand filtration or activated carbon filtration, one-stage filtration is used, in which iron and manganese removal occurs. In turn, Poznan and Torun use the mechanical (Torun only), sand and activated carbon filtration. But in all these cities, the disinfection method is used: with chlorine dioxide in Torun and Poznan; with UV radiation in Gdynia, with sodium hypochlorite in Gliwice and Czestochowa, and with ozone in Czestochowa. Also, Czestochowa is the only city, which in water treatment process uses denitrification method, which aim is nitrates elimination (Table 7).

In turn, in Sosnowiec, Lublin and Wroclaw, four methods of water treatment are used in the whole water treatment process: sand and carbon active filtration in Sosnowiec and Wroclaw, one or two-stage filtration with softening, manganese and iron removal, coagulation and flocculation in Sosnowiec. The disinfection method in these cities is applied as follows: with chlorine dioxide in Sosnowiec and Lublin, with sodium hypochlorite in Lublin and with ozone in Wroclaw.

***Table 7.*** *Polish cities with a smaller number of water treatment methods used in the water treatment process*

| City/ methods | Infiltration | Filtration | | | One or two-stage filtration | | | Aerating and stripping | Coagulation and flocculation | Disinfection | | | | Denitrification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mechanical | Sand filtration | C active | Softening | Mn removal | Fe removal | | | with $ClO_2$ | with UV radiation | with NaOCl | with $O_3$ | |
| Bielsko-Biala | | | | | | | | | | | X | | | |
| Gliwice | | | | | | X | X | X | | | X | X | | |
| Kielce | | | | | | | | | | | | X | | |
| Sosnowiec | | | X | X | | | | | X | X | | | | |
| Radom | | | | | | | | X | | | | | | |
| Czestochowa | | | | | | X | X | | | | | X | X | X |
| Gdynia | | | | | X | X | X | X | | | X | | | |
| Bialystok | | | X | | | | | | | X | | | | |
| Lublin | | | | | | X | X | | | X | | X | | |
| Poznan | X | | X | X | | | | X | | X | | | | |
| Wroclaw | X | | X | X | | | | | | | | | X | |
| Lodz | | | | | | | X | | | | | | | |

***Source:*** *Own elaboration.*

In Bialystok, only three water treatment methods are used in the whole water treatment process: aerating and stripping, sand filtration and disinfection with chlorine dioxide. The water quality in Lublin is widely recognized as one of the best in Poland. And in cities such as Bielsko-Biala, Kielce, Radom and Lodz, the water treatment process includes only one water treatment method - disinfection with UV radiation in Bielsko-Biala, disinfection with sodium hypochlorite in Kielce, aerating and stripping in Radom and iron removal in Lodz.

In the case of these cities, this is caused by the fact that the water in these cities has decent quality and does not require a few water treatment methods for its further purification. Radom water is considered as one of the most delicious in Poland. It is acquired from 42 wells with depth up to 300 m, and its high quality allows it to drink straight from the tap. The water in Lodz is also considered as one of the best and cheapest in Poland, it is drawn in 90% of deep wells, and it has such a good quality that it does not require any treatment. The same applies to Bielsko-Biala and Kielce - water from deep wells is so good that it involves disinfection only. In Kielce, due to water physicochemical and bacteriological high quality, the acquired water is not subjected to treatment and disinfection. However, due to the quite large distance between water intake and the city - 12 km, the water is disinfected with sodium hypochlorite.

## 5. Conclusion

The purpose of this article was to carry out a comparative analysis of the water treatment methods used in water treatment processes which occur in Polish cities, whose population exceeds 150 thousand citizens. The conduction of this analysis was possible thanks to the information obtained from Municipal Water Supply and Sewerage Companies from each city. From the group of selected cities, only Olsztyn did not provide any necessary information, which resulted in the inability to conduct an analysis. Regarding the obtained results of the study, the following conclusions can be drawn:

– to the most often used methods in water treatment processes, one can include: aerating and stripping, sand and carbon active filtration and disinfection with chlorine dioxide. It confirms that surveyed Water Treatment Plants use a method that is one of the most effective solutions to ensure the high quality of treated water. Frequent use of the carbon active filtration method indicates that Water Treatment Plants choose methods that are perceived as the most modern, most effective, and ecologically efficient. In turn, the frequent use of methods: sand filtration and disinfection with chlorine dioxide, confirms that, next to the most modern methods, proven techniques in terms of efficiency and environmental performance are used as well,
– the least used methods in the water treatment process are denitrification, sedimentation, one or two-stage filtration, infiltration mechanical filtration and disinfection with UV radiation and with ozone. But the ozone is frequently used as a part of preliminary and indirect ozonation. Denitrification method is used in one city only – Czestochowa – which indicates that water in that city, is characterized by a too high content of nitrate. Sedimentation is often treated as a variant of filtration, and it is only used in cases where water requires an additional filtration. One or two-stage filtration methods are used only in cases where water from the intake is characterized by too high levels of iron and manganese. Thus, the rare use of this method proves that water in Poland is not characterized by too high levels of these compounds. Infiltration and disinfection with UV radiation and with ozone, in turn, are perceived as one of the most modern methods. They also have a high cleaning efficiency, which leads to the conclusion that they shall become more and more common over time. During the information acquisition for the analysis, many Water Treatment Plants have reported information about planned investments, which will introduce the disinfection with UV radiation for use,
– mostly, Water Treatment Plants use several selected methods to get the highest quality of drinking water. The most complex process of water treatment takes place in Gdansk and Szczecin. In both these cities, the whole water treatment process includes ten different water treatment methods. In the two largest cities in Poland - 8 (Warsaw) and 7 (Cracow) different water treatment methods are used in the water treatment process. Therefore, it can be concluded that the number of methods used does not depend on the size of the city, but it depends on the quality of the water extracted from the river or deep wells. It is confirmed by the case of Lodz – this is the third biggest

city in Poland in terms of the population, and it is characterized by the fact that the water treatment process includes one method only - iron removal. It is caused by the fact that the water in this city is characterized by very high quality.

To sum up, on the one hand, it can be assumed that Water Treatment Plants in Poland use the most modern and the most effective methods, but on the other hand, limiting the analyzed sample to the cities with more than 150,000 citizens does not indicate whether the same applies to the whole country. It can only be assumed that in the largest cities, the management of water treatment processes is proceeding correctly. The same takes place in other cities. Therefore, it would be worthwhile to carry out a very extensive study to get a comprehensive picture of the management of water treatment processes and the methods used. Generally, Poland's attitude to water quality management is on the right track, and it can be clearly stated that the authorities correctly implement the assumptions of both EU directives and international regulations.

What is more, the overall objective of municipals is keeping up the standards of a good quality of water in terms of sustainable development and economic advantages. The eco-friendly trend towards respecting the natural aquatic resources and not wasting water is visible and widely spread in Poland, and the water quality as the factor influencing the healthy life of citizens belongs to the fundamental aspects of sustainable development. The same, the attitude to water as a valuable source also changes among the people who increasingly treat drinking water as equally healthy and qualitative as bottled water.

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