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Article

Variability of Drinking Water Quality on the Basis of Analysis of Qualitative Monitoring from a Selected Water Supply Network Located in South-Eastern Poland

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Abstract: Various groups of contaminants can be found in water intended for human consumption, such as bacteria, viruses, chemicals, and heavy metals. Many of these contaminants can cause serious health problems, so it is extremely important to ensure that water quality meets current standards. The main objective of this study was to analyze and evaluate the variability of drinking water quality in a selected water supply system located in the southern part of Poland. The results of the research and analysis presented in the study were prepared on the basis of test reports carried out by the water supply company during the operating years 2018–2022. A total of 28 indicators from the group of physicochemical and microbiological parameters were analyzed: color, turbidity, pH, electrical conductivity, nitrates, nitrites, chlorides, chromium, aluminum, cadmium, magnesium, manganese, copper, nickel, lead, mercury, sulfates, total iron, oxidizability, chloroform, total THM (Trihalomethanes), total organic carbon, chlorites and chlorates, *Escherichia coli*, *Enterococci*, *Coliform Bacteria*, *Clostridium perfringens* (with spores), and total hardness. The results obtained were compared with national and European standards. The analyzed tap water was characterized by a stable physicochemical composition and did not exceed microbiological parameters. The only parameter that would not meet the acceptable value is chromium. Its value in each of the analyzed months was <3.0 μg/L, while the new directive tightens the requirements to 0.25 μg/L. The water supply network operator should take action to reduce the amount of chromium in tap water so that it follows the introduction of new regulations on the quality of drinking water.

Keywords: contaminants; right to water; safe water; water monitoring; water quality indicators

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1. Introduction

Delivering water to its consumers in the right quantity, at the required pressure and quality, in accordance with the applicable national and European regulations, is the basic task of the water distribution system [1–7]. The results of water quality tests provided by operators, i.e., physical, chemical, and bacteriological indicators, often refer to tests carried out on water samples taken at water treatment plants (WTPs). The initial values of individual indicators change at different water sampling points [8]. This change is usually related to the time the water has been in contact with the internal surface of the pipes. It is extremely important to have knowledge of the dynamics of variability of water quality parameters, based on many years of observations and analyses of hydraulic parameters of water supply network operation [9].

In recent years, there has been a big interest in the chemical and biological stability of water in water supply systems, and the impact of changes in water quality on the health risks of its consumers [7,10–16]. This is directly related to the development of analytical and epidemiological methods on the impact of individual water components on human health and life. The quality of raw water taken for the purpose of supplying water to the population determines to a large extent whether water is chemically and biologically stable.

The stability of water in the water supply system also depends on the correctly selected water treatment technology and the technological reliability of all processes included in its composition. It is particularly important, during the removal of mineral and biological substances from water, to minimize the amount of micropollutants introduced together with chemical reagents and by-products generated in oxidation and disinfection processes, which have an adverse effect on human health. Changes in water quality, their impact on human health, and water stability are the subjects of many research works in Poland, Europe, and the world [7–16]. During the transport of water through water supply pipes, deterioration of the organoleptic properties of water is often observed, i.e., taste, smell, color, and turbidity. In the case of water disinfected with chlorine or chlorine dioxide, the amount of disinfection by-products in the water supply increases.

The quality of the water for consumers is largely determined by the technical condition of the network, interruptions in the operation of the water supply system, and hydraulic conditions in the water supply network as well as the time the water is retained in the system, the so-called water age. The composition of water at the consumer level is determined by many factors. The common cause of deterioration of water quality is corrosion processes occurring on the internal walls of water supply pipes, both in internal water supply systems (in buildings) and the water supply network itself [10,13,15]. The corrosion process is of course influenced by the quality of water supplied from the water treatment plant, but also by the material from which the water supply network is made. Today, materials such as PE (polyethylene), PP (Polypropylene), PVC (Poly(vinyl chloride)), and PE-HD (high-density polyethylene 0.935–0.970 g/cm^3) are used to build water supply networks, but the existing water supply infrastructure in many cities was built in the 1970s and 1980s and steel and cast iron were often used as construction materials.

Corrosion processes occurring in the water supply network and in internal water supply installations, which may be exacerbated by the presence of aggressive carbon dioxide in the water, are among the most common causes of water quality deterioration. The speed of the corrosion process is mainly determined by the type of material used to build the water supply network and the composition of the water carried [10,17–24]. The technical condition and age of the network, interruptions in the operation of the water supply system, unstable hydraulic conditions of the system operation such as flow rate and water pressure, and the time of water retention in the system (the so-called water age) largely determine the variability of the water quality at the consumer level. The literature on this subject also states that the quality of water at the consumer level is also affected by the formation of biofilm on the internal surfaces of water supply pipes [10,19,22–30].

The presence of biofilm in the water supply network contributes to an increased risk of secondary contamination of tap water [7,10]. The main factors causing changes in water quality in the water supply network, and thus increasing the likelihood of secondary water contamination, include the type of material from which the water supply network is made, changes in flow rate, low flow rate, rapid changes in pressure causing local negative pressure, poor technical and sanitary conditions, corrosion, improper selection of treatment technology causing water instability in the network, residue of large doses of unused disinfectant, presence of biochemical processes in the network, improperly conducted repairs and renovations of the network, replacement of pipelines and fittings, and direct connection of household and industrial appliances to the water supply network.

The safety of water supply for consumers is influenced by a number of factors related to both the water production and distribution processes, starting from the water intake and technological processes, through water pumping stations and water supply tanks, to water transport through the water supply network. Among the potential threats affecting the quality of water in the water supply network are microbiological and physicochemical contamination [10,26,31–34]. Microbiological contamination may, although not always, constitute a source of serious threat to human health and life; it all depends on the type of microorganisms contained in the water [31–33]. It is obvious that the quality of water in terms of microbiology is subject to changes, and the presence of pathogenic microorganisms in water reduces the safety of the water supply, thereby increasing the risk of diseases caused by, for example, *E. coli*, *Salmonella* and *Campylobacter bacteria*, viruses such as rotavirus and norovirus, and parasites such as *Giardia lamblia* and *Cryptosporidium*. Physic chemical contamination resulting from secondary water contamination and posing a risk to the health of water consumers can be divided into contamination resulting from contact of water with materials used to build the network, disinfection by-products (formed from chlorine or hypochlorite and chlorine dioxide), and products of biological and electrochemical corrosion and biofilm contamination [10,26,28,29,31–38]. The group of threats also includes the interruption of the continuity of water supply, as a result of a failure of the water supply network [35].

The results of the research and analysis presented in the study were prepared on the basis of test reports carried out by the water supply company during the operating years 2018–2022 in selected cities in Poland. A total of 28 indicators from the group of physicochemical and microbiological parameters were analyzed. The data were obtained from water quality monitoring carried out at selected control points in the water distribution system. The obtained data were compared with standards applicable in Poland and the European Union. Developing appropriate management strategies to maintain good water quality has always been challenging for water utilities.

The main objective of the article is to analyze the quality parameters of tap water and to present their characteristic variability. In order to achieve the main objective, specific objectives were identified, which include the selection of an appropriate water sampling methodology and a methodology for determining individual physicochemical and microbiological parameters. As part of the monitoring, a comprehensive physicochemical analysis of the water and the content of heavy metals in the water samples tested was carried out. The results are based on the results of the qualitative monitoring carried out in the analyzed research water distribution subsystem (WDS) in the years 2018–2022. The results of the analysis can be used by water network operators to assess the condition of water pipes as the main subsystem responsible for supplying water to its consumers.

2. Selected Organoleptic Indicators Defining the Quality of Tap Water

One of the main factors that affects the deterioration of the organoleptic parameters of water is the presence of metal ions in water. One of them is iron, the maximum permissible concentration of which is 0.2 mg/L, while the taste deteriorates at a concentration of 0.05 mg/L [10–12,20,25,38]. Water containing iron is characterized by a metallic smell and taste and is cloudy. This compound drastically reduces the quality of water and reduces the comfort of its use. It has an adverse effect on the installation and household appliances connected to it. The metallic aftertaste is very noticeable in coffee, tea, and cooked dishes. In addition, water with a large amount of iron creates rusty stains on the bathtub, sink, and faucets, which not only look very unsightly but are also difficult to remove. It is also not suitable for washing, because instead of washing, it stains clothes, leaving yellow or gray stains on them. Dishes washed in such water become very dull and permanent streaks appear on them. The reason for an increased iron concentration in water may be an old and corroded internal water system in the apartment/block/building [10–12,25].

The presence of chlorine in water can also result in a deterioration of the organoleptic properties of water, mainly by giving the water a specific smell. According to the regulation on the quality of water intended for consumption [1,3], the concentration of chlorine in drinking water cannot exceed 0.3 mg/L. Despite the permissible value of chlorine in water, water consumers can clearly feel its taste and smell.

Another factor influencing organoleptic changes in water is the presence of suspended sediment, i.e., water hardness. Carbonate hardness is related to the presence of compounds in the form of calcium and magnesium bicarbonates, carbonates, and hydroxides in water. This is part of the total hardness of water, which disappears after boiling—the so-called transient hardness. On the other hand, non-carbonate hardness is caused by the presence of calcium and magnesium salts, e.g., sulfates, chlorides, nitrates, and silicates, and does not change when heating and boiling water. In Poland, according to the applicable regulation [1,3], the hardness of water intended for human consumption must be in the range of 60–500 mg $CaCO_3$/L. The taste threshold for calcium ions is in the range of 100–300 mg/L, depending on the accompanying anions, but higher concentrations are also acceptable for consumers. Hardness levels above 500 mg/L are generally considered unacceptable from an organoleptic point of view. The analyzed tap water is characterized by hardness in the range of 150 ÷ 350 mg/L (the average hardness value is about 250 mg/L $CaCO_3$ with the upper permissible value of 500 mg/L $CaCO_3$) and is within the limits specified in the regulation. In medium-hard water, the content of calcium ions is about 200 mg/dm^3, while the content of magnesium ions is about 15 mg/L (the standard for magnesium is 7 ÷ 125 mg/L).

The presence of calcium and magnesium in water is recommended for human health. Calcium is a component of bones, and magnesium is necessary for the proper functioning of the circulatory and nervous systems. Therefore, very soft waters are harmful to the body, because they can flush calcium and magnesium compounds from the body, increasing the risk of rickets in children and heart attacks in adults. Using very hard water is undesirable for technical and economic reasons. High water hardness causes scale to precipitate on sanitary equipment and fittings, which affects, among other things, the use of larger amounts of cleaning agents. Water consumers may also have doubts about the white color of water cloudiness after pouring it into a glass. The most common cause of cloudy water is its aeration, which is not harmful to health [10,38,39].

The technical condition of internal water supply systems in single-family houses/blocks/public utility buildings has an impact on the quality of water at the draw-off points. The quality of water supplied by the water supply company in the analyzed city may deteriorate as a result of improper use and improper maintenance of internal water supply systems in buildings by their owners/managers.

3. Materials and Methods

The process of analyzing and assessing the variability of drinking water quality is shown in Figure 1.

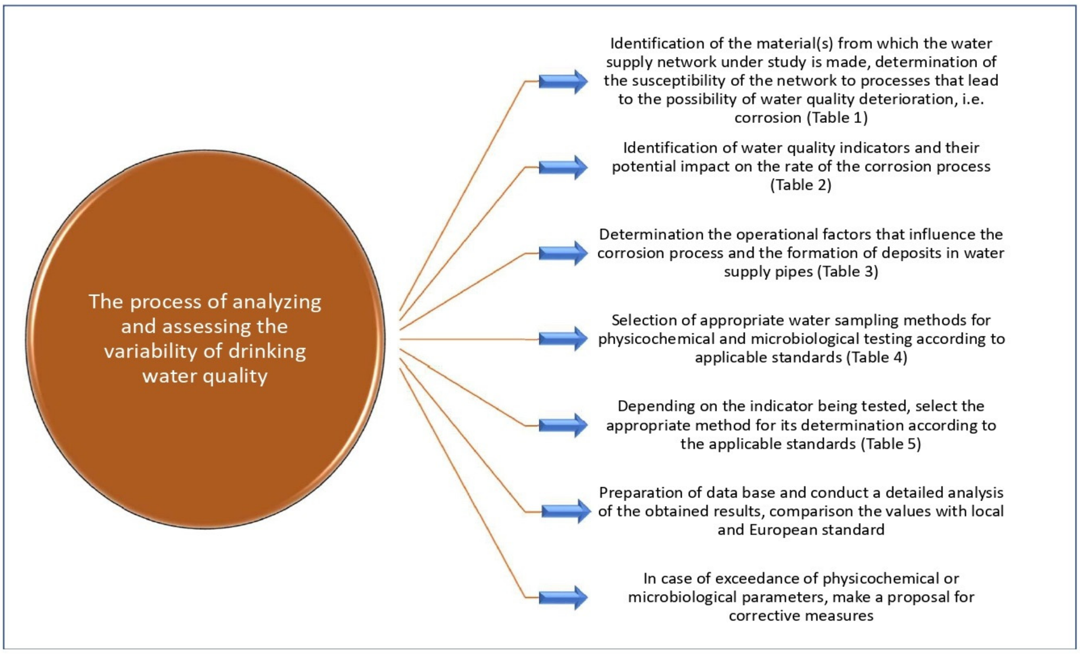


Figure 1. Steps of analyzing and assessing the process of the variability of drinking water quality.

Table 1 shows the corrosion resistance of various materials used in the construction of water supply networks and internal water supply systems.

Table 1. Corrosion resistance of various materials used in the construction of water supply networks and internal water supply systems [40].

Material from Which the Water Pipe Is Made	Susceptibility to Corrosion
Plain carbon steel	The material that is most susceptible to corrosion.
Gray cast iron	A material that is susceptible to corrosion.
Nodular cast iron	A material that is more susceptible to corrosion than gray cast iron.
Steel or cast iron with concrete covering	Materials with good resistance to corrosion.
Galvanized steel	Anti-corrosion treatment increases corrosion resistance, but passive coatings dissolve causing a possible increase in zinc concentration in the water at the point of use
Asbestos–cement	Leaching of calcium and magnesium compounds has been observed in waters containing aggressive carbon dioxide
Plastics (PVC, polyamide, PEHD, PE, PP)	Corrosion resistant. Monomers and plasticizers are observed to be washed out of pipelines by tap water. Pipes used to build the network must have certificates that allow the material to come into contact with water. Biofilms form on the internal surfaces of water pipes.
Copper	Material used in the construction of internal water supply networks (ground and hot water installations). The speed of the corrosion process depends on the quality of the water supplied from the external water supply network. A basic mistake is to make internal installations from different materials. In installations made of a combination of steel, galvanized steel, and copper pipes, corrosion quickly leads to the destruction of the water installation. When making internal installations from copper pipes, the influence of water quality on the speed of copper compounds leaching by the water supply is generally not taken into account.

Table 2 shows the influence of selected factors on the corrosion process and the formation of corrosion deposits in water supply systems [40] while Table 3 presents the main operating factors and their influence on the corrosion process and the formation of deposits on the internal walls of pipes [40].

Table 2. Factors influencing the corrosion process and the formation of corrosion deposits in water supply systems [40].

Water Quality Indicator	Influence on the Rate of the Corrosion Process
Dissolved oxygen	High concentrations increase the corrosion rate. In the absence of oxygen and chlorine, anaerobic processes may occur in the sediment zone, as well as the denitrification process and the formation of sulfides by the reduction of sulfates. These processes only occur in the presence of organic compounds in the water (sediments). Reducing the amount of oxygen in water increases the rate of leaching of corrosion products of steel and cast iron pipes.
Aggressive carbon dioxide	This causes intensification of corrosion as a result of the destruction of passive coatings.
pH	High pH slows down the corrosion of steel and cast iron; low pH intensifies this process.
Total hardness and alkalinity of water	High water hardness inhibits corrosion, especially when calcium carbonate settles on the surface of the pipe walls. Disturbance of the carbonate balance can cause the precipitation of carbonate minerals in the pipes and intensive overgrowing of the pipes with sediments.
Sulfates and chlorides	The increase in the concentration of these ions intensifies corrosion, as the specific conductivity of water increases. The process depends on the alkalinity of water and the formation of passive carbonate coatings.
Nitrates	These cause intensification of the corrosion rate.
Copper	These cause intensification of the corrosion rate.
Iron and manganese	Intensification of the corrosion process rate due to uneven precipitation of deposits on the surface of steel and cast iron pipes and the formation of galvanic cells. The presence of iron and manganese ions in tap water promotes the growth of ferruginous and manganese bacteria.
Sodium and potassium	They increase the electrical conductivity of water, which accelerates corrosion.
Sulfur and hydrosulfuric ion	These cause intensification of the corrosion process as a result of the growth of sulfur bacteria.
Ammonium	This causes intensification of the corrosion process due to the development of nitrifying bacteria.
Free chlorine	This increases the intensity of the electrochemical corrosion process of steel; however, it reduces biological corrosion.
Conductivity of water	An increase in the indicator causes corrosion.
Phosphates and humate compounds	These are inhibitors of corrosion processes.

Table 3. Operational factors influencing the corrosion process and the formation of deposits in water pipes [40].

Operational Factor	Influence on the Speed of the Corrosion Process
Technical condition	As the age of the pipes increases, their technical condition deteriorates, and the corrosion rate increases. Also, poor quality of the network construction increases the probability of corrosion.
Flushing and cleaning of pipes, replacement/renovation of damaged pipes or their sections, proper maintenance of pipes and assembly, use of control, measurement, and safety fittings	These factors reduce the corrosion rate.
Water flow speed and its daily changes, changes in its flow direction and pressure	Low flow rates increase the possibility of corrosion due to the longer contact time of water with the pipe, while high flow rates cause the corrosion products to be torn off from the inner surface of the pipes.
Character of water flow	Turbulent water flow increases the corrosion rate.
Water distribution and daily variability	Small water consumption increases the intensity of corrosion, and large water consumption contributes to the removal of corrosion products from the internal surfaces of pipes.
Method of designing a water supply network	Oversizing the network in the design phase, e.g., by taking into account the water demand for fire-fighting purposes, causes a decrease in its flow rate, which increases the possibility of corrosion.
Water residence time in the water supply network	The extension of water age causes its quality to deteriorate. This phenomenon is particularly visible at the ends of the network.
Mixing of water from different water intakes or water treatment plants in the water supply system	Frequent changes in water flow direction and composition increase the potential for minerals to settle in the water. When the direction of water flow changes, sediment is transported from the pipelines.

This study covered the results of water quality parameters treated in the water supply network in the city. Based on data provided by the network operator, reports of water quality results in the water supply network, prepared by the accredited central laboratory located at the water treatment plant, were analyzed. Water samples for testing were collected in accordance with the PN-EN ISO 5667-5:2003 Water quality—Sampling—Part 5: Guidelines for sampling of drinking water and water used for food and beverage production [41]. Table 4 shows the methodology and the method of collecting water samples for testing, and Table 5 presents the method of determining the selected indicators, range of measurements, and literature sources.

A detailed and complete database of water quality for the years 2018–2022 was analyzed and assessed. At one control point located in the water supply network, 6 samples were collected for testing per quarter (twice a month). The analysis required sorting, analyzing, and verifying the data. Average values for individual parameters were developed for the analysis, for each quarter. In the case of reports with average results for the entire water supply network, the following water quality parameters were selected for analysis: color, turbidity, pH, conductivity, nitrates, nitrites, chlorides, chromium, aluminum, cadmium, magnesium, manganese, copper, nickel, lead, mercury, sulfates, total iron, oxidizability with KMnO4, chloroform, total THM (Trihalomethanes), total organic carbon, total chlorites and chlorates, *Escherichia coli*, *Enterococci*, *Coliform Bacteria*, *Clostridium perfringens* (with spores), and total hardness. The results were presented in tabular form. The results of the variability of a given parameter over time are also presented graphically. Statistical analysis and presentation in the form of a graph were not performed for water quality parameters, the results of which were outside the detection range of the laboratory equipment used for testing. The obtained results of water quality monitoring tests, both for the entire water supply network and selected control points, were compared with the requirements for individual parameters specified in the applicable Regulation of the Minister of Health on 7 December 2017 on the quality of water intended for human consumption [3] and with the requirements set by the EU specified in Directive (EU) 2020/2184 of the European Parliament and of the Council on 16 December 2020 on the quality of water intended for human consumption [1], the provisions of which have not yet been implemented in Polish national law. As many of the reports received from the water utility in the analyzed city did not include tests of all water quality parameters for each sample taken at the water collection point, it was not possible to carry out a detailed analysis of the variability of all the parameters tested in the accredited central laboratory of the water utility.

Table 4. Types of packaging and their filling method for the purpose of performing tap water quality analyses, based on [40,41].

Analysis	Type of Packaging/Container	Filling Method
Physicochemical tests		
Basic tests: color, turbidity, pH, conductivity, ammonium ion	Plastic bottles with a capacity of 1 dm^3 closed with plastic caps	Rinse the bottle with the water to be tested and fill it to the top, pouring a small stream down the walls (which prevents aeration of the sample).
Smell, taste	Glass bottles, with a capacity of 500 mL, closed with glass stoppers	
Basic tests + hardness, chlorides, nitrites, oxidizability, calcium, fluorides, nitrates, sulfates, magnesium	Plastic bottles with a capacity of 2 dm^3 closed with plastic caps	
Iron, manganese	Plastic bottles with a capacity of 250 cm^3 closed with a cap, containing 2.5 cm^3 H_2SO_4	Fill the bottle to the neck; do not rinse out the fixative. The durability of the samples after acidification is 30 days.
Metal: lead, cadmium, chromium, nickel, copper, selenium, antimony, sodium, aluminum, arsenic	Plastic bottles with a capacity of 250 cm^3 closed with a cap, containing 2 cm^3 HNO_3	Fill the bottle to the neck; do not rinse out the fixative. The durability of the samples after acidification is 30 days.
Mercury	Glass bottles of 100 mL with a blue cap, containing 2 mL of hydrochloric acid solution. The durability of the samples is 30 days	Collect samples in 100 mL bottles. Fill with water to the top, avoiding washing out the acid.
Free chlorine	Dark glass bottles with a capacity of 250 cm^3 with a narrow neck and a ground glass stopper	Fill the bottle and close it so that no air bubbles remain under the cap.
ΣTHM (Trihalomethanes): bromoform, trichloromethane, bromodichloromethane, dibromochloromethane	Glass bottles of 250—300 cm^3 capacity, closed with ground glass stoppers containing sodium thiosulfate crystals	Fill the bottle and close it so that no air bubbles remain under the cap.
Bacteriological tests		
Basic research: coliform bacteria, *Escherichia coli*	Sterile, glass bottles with a capacity of 250–300 cm^3, closed with ground glass stoppers; chlorinated water is collected in the bottle containing sodium thiosulfate	Fill the bottle with bacteriological water up to the bottle's neck (ensuring an air cushion above the water) and close tightly, avoiding contamination of the cap.
Basic tests + *Enterococci*, total number of microorganisms at 22 ± 2 °C		
Sulfite-reducing *clostridia*, *Pseudomonas aeruginosa*, *Clostridium perfringens* (including spores)	Sterile, glass bottles with a capacity of 500 cm^3 or 1000 cm^3 closed with ground glass stoppers; we collected chlorinated water in the bottle containing sodium thiosulfate	

Table 5. Methods for determining selected water quality indicators, based on [42].

Indicator Measurement Range Method	Reference Document
Turbidity Range: (0.2–40) NTU Nephelometric method	PN-EN ISO 7027-1:2016-09 [43]
Nitrates V Range: (2.5–50) mg/L Ion chromatography method with conductometric detection (IC-CD)	PN-EN ISO 10304-1:2009 + AC:2012 [44]

Table 5. *Cont.*

Indicator **Measurement Range** **Method**	**Reference Document**
Nitrates III Range: (0.05–1) mg/L Ion chromatography method with conductometric detection (IC-CD)	PN-EN ISO 10304-1:2009 + AC:2012 [44]
Chlorides Range: (2.5–250) mg/L Ion chromatography method with conductometric detection (IC-CD)	PN-EN ISO 10304-1:2009 + AC:2012 [44]
Aluminum Range: (0.04–1) mg/L Spectrophotometric method	PN-92/C-04605/02 [45]
Total calcium and magnesium content (total hardness) Range: (10–625) mg/L $CaCO_3$ Titrimetric method	PN-EN ISO 6059:1999 [46]
Manganese Range: (0.015–1.0) mg/L Spectrophotometric method	PN-92/C-04590/03 [47]
Copper Range: (0.02–50) mg/L Flame atomic absorption spectrometry (FAAS)	PN-ISO 8288:2002 Method A [48]
Sulfate $SO4_4$ Range: (5–250) mg/L Ion chromatography method with conductometric detection (IC-CD)	PN-EN ISO 10304-1:2009 + AC:2012 [44]
Total Iron Range: (0.02–20.0) mg/L Spectrophotometric method	PN-ISO 6332:2001 [49]
Chlorites Range: (0.05–1.0) mg/L Ion chromatography method with conductometric detection (IC-CD) Chlorates Range: (0.1–2.0) mg/L Ion chromatography method with conductometric detection (IC-CD)	PN-EN ISO 10304-4:2022-08 [50]
Escherichia coli Membrane filtration method	PN-EN ISO 9308-1:2014-12 +A1:2017-04 [51]
Enterococci Membrane filtration method	PN-EN ISO 7899-2:2004 [52]
Coli Bacteria Membrane filtration method	PN-EN ISO 9308-1:2014-12 +A1:2017-04 [51]
Clostridium perfringens Membrane filtration method	PN-EN ISO 14189:2016-10 [53]

4. Characteristics of the Study Object

The operator managing the collective water supply system (CWSS) has a modern and efficient water quality control system, which includes analyses of the quality of raw water at the water treatment plant and the protective station protecting the water intake against accidental contamination, ending with comprehensive tests of water supplied to the municipal water supply network and at the network ends (defined control points located on the water supply network). The CWSS operator is responsible for the operation of the water supply and sewage network throughout the city. The water supply network supplies an area with a high degree of urbanization and a diverse nature of water consumers. These include public utility buildings, including administrative buildings, schools, kindergartens, universities, hospitals and clinics, collective and individual housing buildings, hotels, and commercial and service facilities.

The water supply network studied receives water from a surface water inlet located on the river in the southern part of the city. It is a typical mountain river, characterized by variable flows and water quality. The water is taken from two technological lines water treatment plant I (WTP I) and water treatment plant II (WTP II)) located in the southern part of the city. The water treatment plant is owned by the company responsible for water supply [7,35,42].

Water is pumped into the municipal water supply network from the water treatment plant (WTP), cooperating with the surface water intake. The water treatment plant consists of two plants with an average daily capacity of 84 thousand m^3/d: ZI with a capacity of 36.5 thousand m^3/d and ZII with a capacity of 47.5 m^3/d. A number of technological processes take place in the water treatment plant and are aimed at producing water of appropriate quality, meeting the requirements of European and national law. The currently used technological process of water treatment includes the following treatment stages [7,35,42]:

(1) Initial ozonation—During this stage of treatment, color compounds and those causing the smell and taste of water are removed from the water in the oxidation process. The role of the oxidant is played by ozone, which is produced from oxygen in ozone generators. In this process, initial disinfection of water also takes place.

(2) Coagulation using aluminum compounds—Colloids and suspensions that do not settle easily are removed from the water, which determines the turbidity of the water and the intensity of its color, mainly humic compounds, silica, and organic pollutants.

(3) Sedimentation in horizontal settling tanks—Particles with a density greater than that of water are removed from the water, i.e., particles that easily settle, produced in the coagulation process.

(4) Filtration through a sand bed and filtration through an anthracite–sand bed—This ensures the removal of particles with a diameter larger than 0.1 mm from water.

(5) Indirect ozonation—The oxidation process removes the remains of colored compounds and those causing the taste and smell of water. The role of the oxidant is played by ozone, which is produced from oxygen in ozone generators. In this process, the initial disinfection of water also takes place.

(6) Filtration through an activated carbon bed—This includes the removal of dissolved organic compounds. The activated carbon filling of the bed also helps to reduce the content of micropollutants that cause the color, taste, and smell of water.

(7) Pre-disinfection with UV lamps—This is used to increase the microbiological stability of treated water, improve its organoleptic properties, and reduce the doses of disinfectants (chlorine and chlorine dioxide).

(8) Disinfection with chlorine compounds: chlorine dioxide and chlorine gas—This ensures good sanitary quality of water in the water supply network; therefore, this process is used at the end of the water treatment system. The chlorine dioxide needed for disinfection is produced in chlorine dioxide generators from sodium chlorite and chlorine gas.

(9) Water pH correction station using sodium carbonate—Equipping WTP with a system for correcting water pH by periodically using (if necessary) sodium carbonate contributed to the elimination of the corrosive properties of water.

After the treatment process at the WTP, water is delivered to consumers via a system of mains, distribution networks, and home connections. The total length of the water supply network with connections is 1116.9 km. Water flowing out of the WTP supplies the city through mains "0" with a diameter of Φ 1200 ÷ Φ 800 mm and mains no. "1", "2", "3", and "4" with a diameter of Φ 400 mm. The total length of the main network is 98.4 km and is constructed out of cast iron and steel pipes. The distribution network constructed out of cast iron, steel, PE, and PVC has a total length of 676.7 km, and the length of water supply connections is 341.8 km. Additionally, the analyzed CWSS includes the operation of 43 water pumping stations (hydrophores), 18 water tanks with a total capacity of 53 thousand m^3, 10 street springs, and 179 emergency wells. Figure 2 shows the location of the research object; Figure 3 shows the research object (water supply network) together with monitoring points for which a database on the quality of the water supply network was obtained [42].

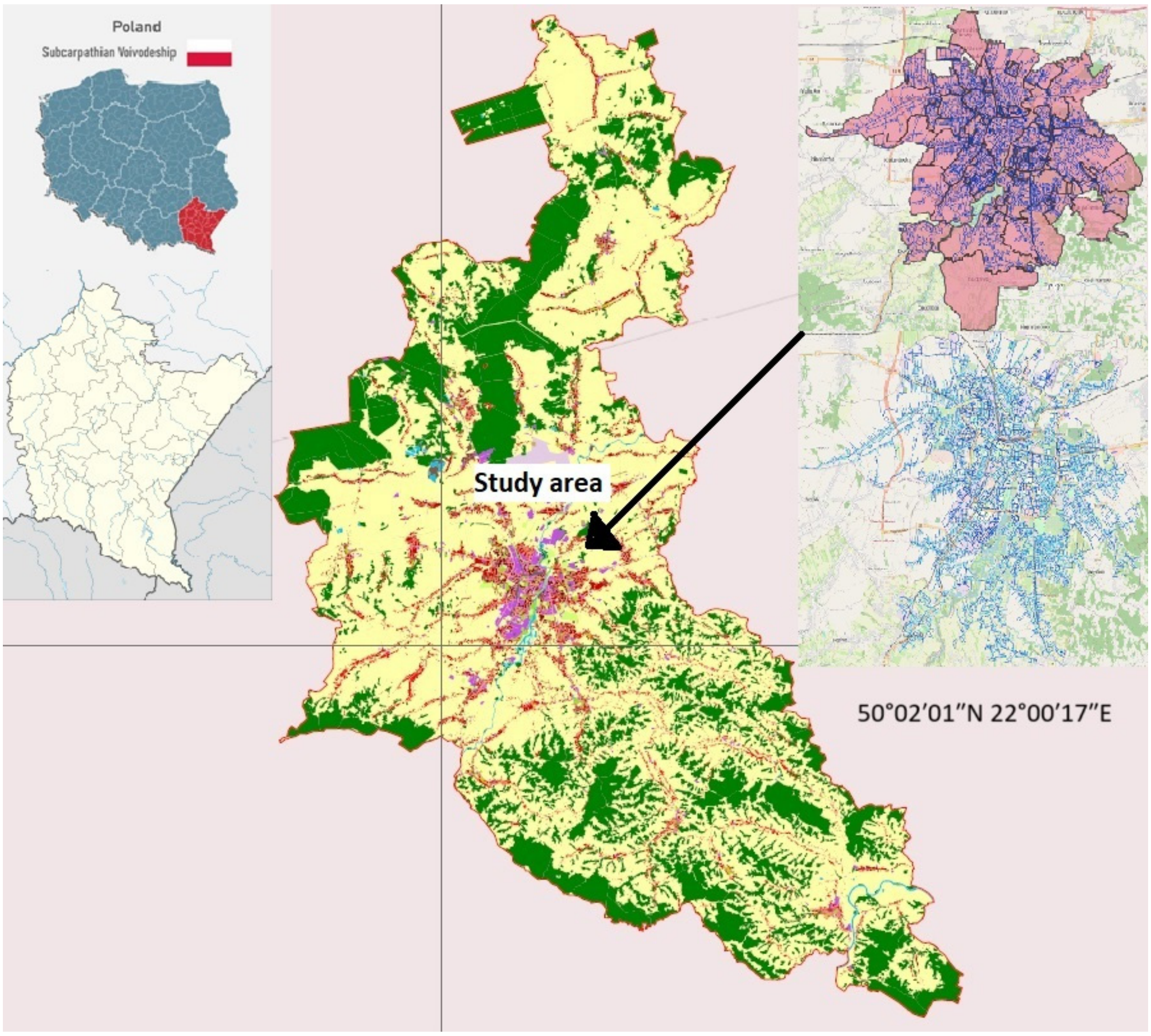


Figure 2. Location map of analyzed water supply network.

For safety reasons and due to the currently dynamically developing situation beyond the eastern border (the research object borders on the western part of Ukraine), detailed data concerning the process of water sampling, the water treatment process, and the location of the water treatment plant facilities are provided.

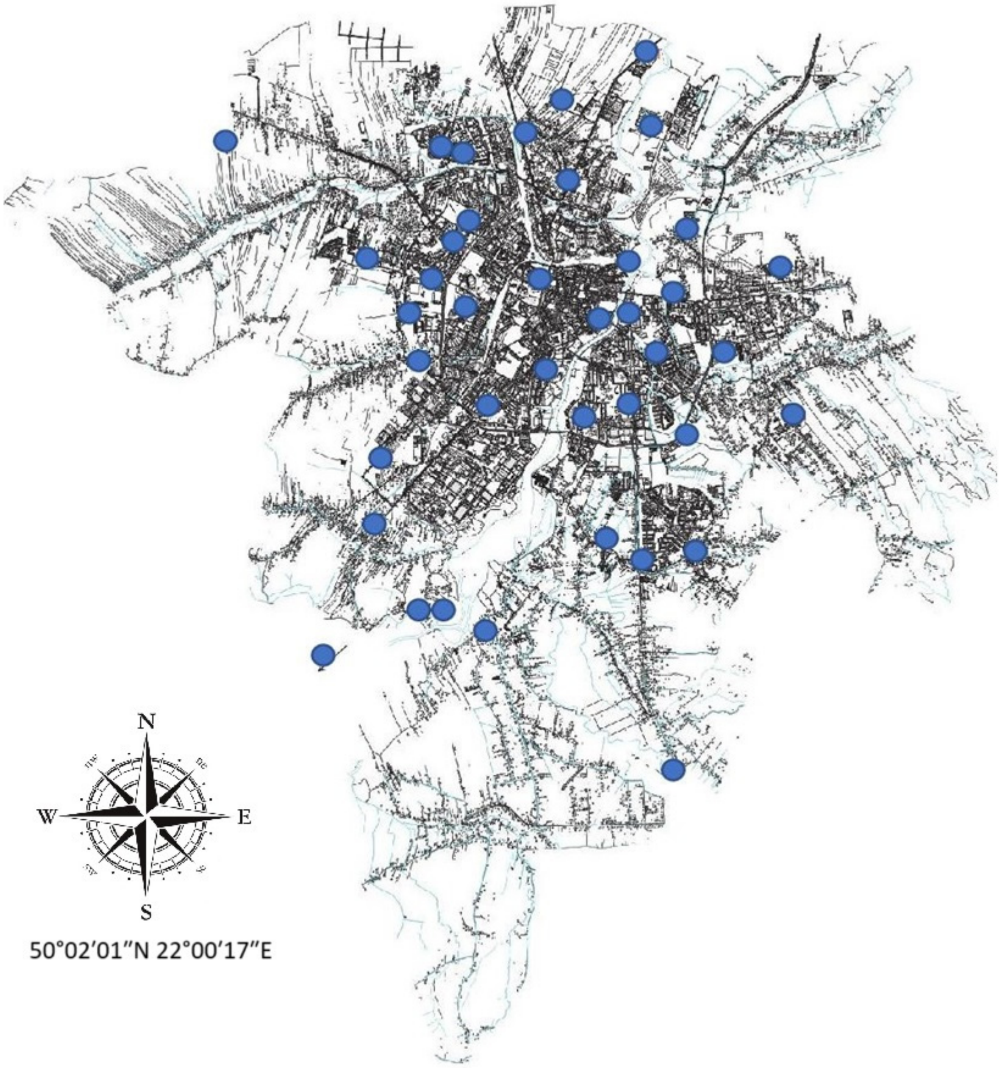


Figure 3. Location of monitoring points of water quality on analyzed water supply network, based on [42].

5. Results

5.1. Qualitative Monitoring Results During the Operating Years 2018–2022

In order to compare changes in water quality in the analyzed period, the results of average values for individual parameters from quarters in 2018–2022 were compared. The obtained results are presented in Tables 6–9. Tables 6–9 show the average values for each parameter. These data were obtained from the accredited laboratory of the water supply company, which is the object of the study.

Table 6. Results of the monitoring of the tested parameters of the water quality in the water supply network for the first quarter of 2018–2022 (own study based on [42,54]).

Indicator	Unit	Quarter I					Limit Value [55]
		2018	2019	2020	2021	2022	
Color	mg/L	<5	<5	<5	<5	<5	Accepted by consumers and without abnormal changes
Turbidity	NTU	<0.20	<0.20	<0.20	<0.20	<0.20	1.0
The pH value	pH	7.80	7.97	7.82	7.70	7.77	6.5–9.5

Table 6. *Cont.*

Indicator	Unit	Quarter I					Limit Value [55]
		2018	2019	2020	2021	2022	
Conductivity	µS/cm	572.7	556.7	602.0	546.7	568.7	2500
Nitrates V	mg/L	8.5	9.0	8.1	10.6	8.2	50.0
Nitrates III	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	0.5
Chlorides	mg/L	26.3	29.0	30.0	30.9	31.5	250.0
Chrome	µg/L	<3.0	<3.0	<3.0	<3.0	<2.2	50.0
Aluminum	µg/L	<40.0	<40.0	<40.0	<40.0	<40.0	-
Cadmium	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	5.0
Magnesium	mg/L	13.9	22.3	12.3	9.9	10.3	7–125
Manganese	µg/L	<20.0	<20.0	<20.0	<20.0	<15.0	50.0
Copper	mg/L	0.004	0.005	0.005	0.004	0.005	2.0
Nickel	µg/L	<4.7	<4.0	<6.3	<4.0	<4.0	20.0
Lead	µg/L	<4.0	<4.0	<2.8	<4.0	<4.0	10.0
Mercury	µg/L	-	<0.10	<0.10	<0.10	<0.10	1.0
Sulfate SO_4	mg/L	36.2	37.0	37.7	32.5	35.0	250.0
Total iron	µg/L	<20.0	<20.0	<20.0	<20.0	<20.0	200.0
Oxidizability with $KMnO_4$	mg/L	0.97	1.04	0.78	0.75	0.72	5.0
Chloroform	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0	0.03
Σ THM (Trihalomethanes)	µg/L	4.2	<1.0	<1.0	<2.3	<1.0	100.0
Total organic carbon	mg/L	1.37	1.67	1.77	1.97	1.63	Without abnormal changes
The sum of chlorites and chlorates	mg/L	<0.18	<0.21	<0.25	<0.17	<0.17	0.7
Escherichia coli	jtk/100 mL	0	0	0	0	0	0
Enterococci	jtk/100 mL	0	0	0	0	0	0
Coli Bacteria	jtk/100 mL	0	0	0	0	0	0
Clostridium perfringens	jtk/100 mL	0	0	0	0	0	0
General hardness	mg $CaCO_3$	256.7	243.0	253.3	237.3	245.7	60–500

Table 7. Results of the monitoring of the tested parameters of the water quality in the water supply network for the second quarter of 2018–2022 (own study based on [42,54]).

Indicator	Unit	Quarter II					Limit Value [55]
		2018	2019	2020	2021	2022	
Color	mg/L	<5	<5	<5	<5	<5	Accepted by consumers and without abnormal changes
Turbidity	NTU	<0.20	<0.20	<0.20	<0.20	<0.20	1.0
The pH value	pH	7.7	7.63	7.62	7.70	7.72	6.5–9.5
Conductivity	µS/cm	556.0	540.0	557.0	540.7	596.3	2500

Table 7. *Cont.*

Indicator	Unit	Quarter II					Limit Value [55]
		2018	2019	2020	2021	2022	
Nitrates V	mg/L	7.5	7.9	6.5	8.2	6.0	50.0
Nitrates III	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	0.5
Chlorides	mg/L	29.1	27.4	29.0	29.4	30.7	250.0
Chrome	µg/L	<3.0	<3.0	<0.5	<3.0	<0.5	50.0
Aluminum	µg/L	<40.0	<45.0	<40.0	<40.0	<40.0	-
Cadmium	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	5.0
Magnesium	mg/L	15.2	13.0	11.7	10.5	12.1	7–125
Manganese	µg/L	<20.0	<20.0	<20.0	<20.0	<15.0	50.0
Copper	mg/L	0.004	0.004	0.005	0.002	0.005	2.0
Nickel	µg/L	6.0	<4.0	<0.5	<4.0	<4.0	20.0
Lead	µg/L	<4.0	<4.0	<0.5	<4.0	<4.0	10.0
Mercury	µg/L	-	<0.10	<0.10	<0.10	<0.10	1.0
Sulfate SO_4	mg/L	32.6	34.7	29.7	31.0	32.7	250.0
Total iron	µg/L	<20.0	<20.0	<20.0	<20.0	<20.0	200.0
Oxidizability with $KMnO_4$	mg/L	0.66	0.78	0.73	0.58	0.83	5.0
Chloroform	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0	0.03
Σ THM (Trihalomethanes)	µg/L	5.1	5.8	6.2	5.6	<1.0	100.0
Total organic carbon	mg/L	1.34	2.13	1.77	1.70	1.61	Without abnormal changes
The sum of chlorites and chlorates	mg/L	<0.19	<0.21	<0.25	<0.15	<0.18	0.7
Escherichia coli	jtk/100 mL	0	0	0	0	0	0
Enterococci	jtk/100 mL	0	0	0	0	0	0
Coli Bacteria	jtk/100 mL	0	0	0	0	0	0
Clostridium perfringens	jtk/100 mL	0	0	0	0	0	0
General hardness	mg $CaCO_3$	244.0	236.7	218.7	236.7	245.0	60–500

Table 8. Results of the monitoring of the tested parameters of the water quality in the water supply network for the third quarter of 2018–2022 (own study based on [42,54]).

Indicator	Unit	Quarter III					Limit Value [55]
		2018	2019	2020	2021	2022	
Color	mg/L	<5	<5	<5	<5	<5	Accepted by consumers and without abnormal changes
Turbidity	NTU	<0.20	<0.20	<0.20	<0.20	<0.20	1.0
The pH value	pH	7.67	7.57	7.57	7.60	7.62	6.5–9.5
Conductivity	µS/cm	592.0	575.3	598.3	595.3	654.3	2500
Nitrates V	mg/L	6.3	5.3	6.1	7.6	5.6	50.0
Nitrates III	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	0.5
Chlorides	mg/L	32.0	40.0	32.3	34.7	43.3	250.0
Chrome	µg/L	<3.0	<3.0	<0.5	<3.0	<0.5	50.0

Table 8. *Cont.*

Indicator	Unit	Quarter III					Limit Value [55]
		2018	**2019**	**2020**	**2021**	**2022**	
Aluminum	µg/L	<61.7	<44.0	<40.0	<46.0	<40.0	-
Cadmium	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	5.0
Magnesium	mg/L	15.4	15.0	12.7	9.8	12.7	7–125
Manganese	µg/L	<20.0	<20.0	<20.0	<20.0	<15.0	50.0
Copper	mg/L	0.004	0.004	0.005	0.002	0.005	2.0
Nickel	µg/L	<4.7	<5.3	1.6	<4.0	<4.0	20.0
Lead	µg/L	<4.3	<4.0	<0.5	<4.0	<4.0	10.0
Mercury	µg/L	-	<0.10	<0.10	<0.10	<0.10	1.0
Sulfate SO_4	mg/L	35.4	37.7	35.3	32.0	42.0	250.0
Total iron	µg/L	<20.0	<20.0	<20.0	<20.0	<20.0	200.0
Oxidizability with $KMnO_4$	mg/L	0.43	0.71	0.57	0.73	1.50	5.0
Chloroform	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0	0.03
Σ THM (Trihalomethanes)	µg/L	7.33	20.73	4.9	7.1	<1.0	100.0
Total organic carbon	mg/L	0.74	2.10	1.95	1.53	1.29	Without abnormal changes
The sum of chlorites and chlorates	mg/L	<0.20	<0.20	<0.25	<0.19	<0.20	0.7
Escherichia coli	jtk/100 mL	0	0	0	0	0	0
Enterococci	jtk/100 mL	0	0	0	0	0	0
Coli Bacteria	jtk/100 mL	0	0	0	0	0	0
Clostridium perfringens	jtk/100 mL	0	0	0	0	0	0
General hardness	mg $CaCO_3$	256.0	251.7	258.7	246.7	240.0	60–500

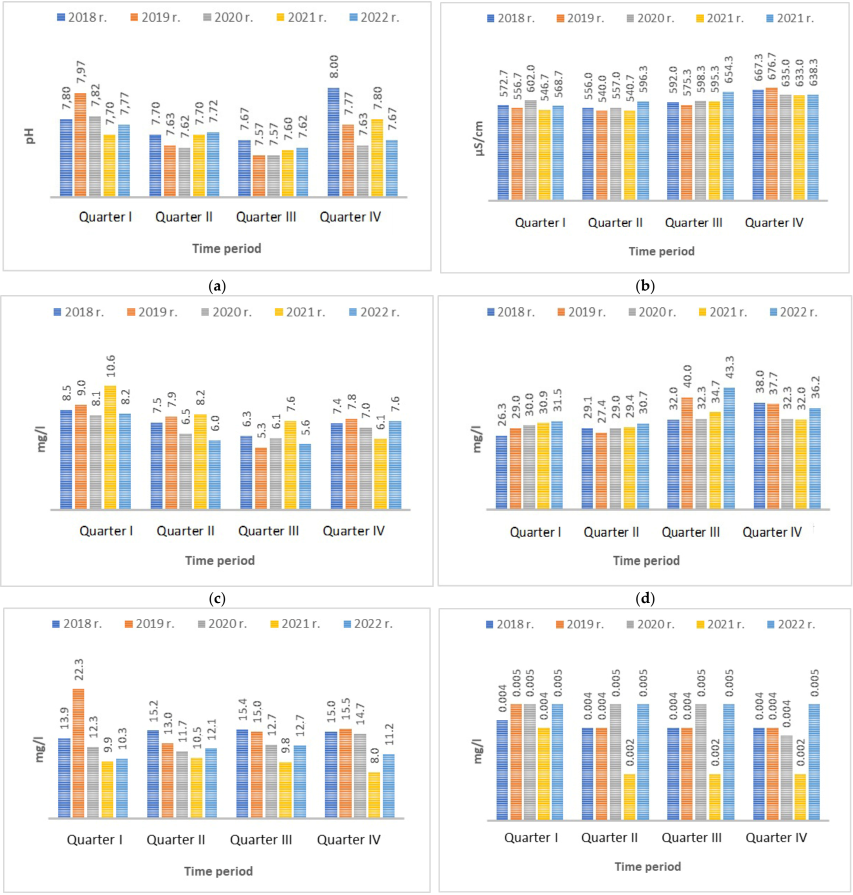
Table 9. Results of the monitoring of the tested parameters of the water quality in the water supply network for the fourth quarter of 2018–2022 (own study based on [42,54]).

Indicator	Unit	Quarter IV					Limit Value [55]
		2018	**2019**	**2020**	**2021**	**2022**	
Color	mg/L	<5	<5	<5	<5	<5	Accepted by consumers and without abnormal changes
Turbidity	NTU	<0.20	<0.20	<0.20	<0.20	<0.20	1.0
The pH value	pH	8.00	7.77	7.63	7.80	7.67	6.5–9.5
Conductivity	µS/cm	667.3	676.7	635.0	633.0	638.3	2500
Nitrates V	mg/L	7.4	7.8	7.0	6.1	7.6	50.0
Nitrates III	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	0.5
Chlorides	mg/L	38.0	37.7	32.3	32.0	36.2	250.0
Chrome	µg/L	<3.0	<3.0	<1.3	<3.0	<0.7	50.0
Aluminum	µg/L	<41.3	<40.0	<40.0	<40.7	<40.0	-
Cadmium	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	5.0
Magnesium	mg/L	15.0	15.5	14.7	8.0	11.2	7–125
Manganese	µg/L	<20.0	<20.0	<20.0	<16.7	<15.0	50.0
Copper	mg/L	0.004	0.004	0.004	0.002	0.005	2.0

Table 9. *Cont.*

Indicator	Unit	Quarter IV					Limit Value [55]
		2018	2019	2020	2021	2022	
Nickel	µg/L	5.0	6.0	<2.4	<2.9	<2.8	20.0
Lead	µg/L	<4.0	<4.0	<1.7	<4.0	<4.0	10.0
Mercury	µg/L	<0.10	<0.10	<0.10	<0.10	<0.10	1.0
Sulfate SO_4	mg/L	40.2	40.0	35.0	35.3	53.0	250.0
Total iron	µg/L	<20.0	<20.0	<20.0	<20.0	<20.0	200.0
Oxidizability with $KMnO_4$	mg/L	0.97	0.97	1.00	0.89	1.23	5.0
Chloroform	µg/L	<1.0	<1.0	<1.0	<1.0	<1.0	0.03
Σ THM (Trihalomethanes)	µg/L	14.0	1.6	<5.1	7.1	<1.0	100.0
Total organic carbon	mg/L	1.53	1.93	1.93	1.87	2.03	Without abnormal changes
The sum of chlorites and chlorates	mg/L	<0.23	<0.20	<0.23	<0.19	<0.20	0.7
Escherichia coli	jtk/100 mL	0	0	0	0	0	0
Enterococci	jtk/100 mL	0	0	0	0	0	0
Coli Bacteria	jtk/100 mL	0	0	0	0	0	0
Clostridium perfringens	jtk/100 mL	0	0	0	0	0	0
General hardness	mg $CaCO_3$	281.0	281.3	255.3	281.0	265.7	60–500

Figure 4 presents the analysis of the variability of selected indicators of the quality of drinking water.



(a) (b)

(c) (d)

(e) (f)

Figure 4. *Cont.*

(**g**) (**h**)

(**i**) (**j**)

Figure 4. Variability of parameters in water network during operational years 2018–2022: (**a**) pH; (**b**) electrolytic conductivity; (**c**) nitrates; (**d**) chlorides; (**e**) magnesium; (**f**) copper; (**g**) sulfate; (**h**) oxidizability with $KMnO_4$; (**i**) total organic carbon; (**j**) and general hardness, based on [55].

5.2. Analysis of Water Quality Variability in the Water Supply Network for the Years 2018–2022

After a detailed analysis of the variability of water quality parameters for the years 2018–2022 presented in point 5.0032, the following conclusions are obtained [42–44]:

- Color—Throughout the period covered by the analysis, the color of the water was at a constant level of <5 mg/L. It met the permissible range of values, was acceptable to water consumers, and had no abnormal changes.
- Turbidity—The results of water quality monitoring in the years analyzed showed that the turbidity of the water remained at a constant level, which was <0.20 NTU, and this is a value acceptable to consumers. The low level of water turbidity throughout the five-year period of research indicates a low content of colloidal particles and suspensions in the tested water.
- pH—The pH value in all analyzed quarters was in the range of 7.57—8.00. The results of the water pH indicator in the water supply network are characterized by low variability over the quarters and in the analyzed period of time. It was observed that in the second and third quarters of each year, the pH was lower than in quarters I and IV. This results from the influence of temperature on water pH. In months when the water temperature is higher, pH decreases. Despite small changes in pH in the quarterly cycle in the analyzed years, the water in the water supply network was stable in terms of pH.
- Conductivity—Average quarterly values ranged from 540.0 to 676.67 µS/cm. When observing the variability of the conductivity of tap water over the quarters, it was noted that electrolytic conductivity was always higher for the fourth quarter in each of the analyzed years. In the remaining quarters, conductivity was at a similar level. There is no significant variability in the electrolytic conductivity of tap water over the years 2018–2022. Small fluctuations are related to changes in the amount of calcium and magnesium ions present in water, which also affect its hardness.
- Nitrates—When analyzing the quarterly concentration of nitrates in tap water in the years 2018–2022, it was observed that their amount was variable. It was noted that in the year 2018, the average quarterly value was 7.43 mg/L, in 2019, it was 7.5 mg/L, in 2020, it was 6.93 mg/L, and in 2022, it was 6.85 mg/L. In 2021, the concentration of nitrates was significantly higher than in other years (the average quarterly value was

8.13 mg/L). Despite this, over the period of time studied, the concentration of nitrates was characterized by average variability, and the permissible values for drinking water were never exceeded.

- Nitrites—By analyzing the amount of nitrites contained in tap water in individual quarters of the five-year study period, it was observed that their concentration in tap water remained at a constant level and amounted to <0.05 mg/L.
- Chlorides—After observing the variability of chloride content in water in the water supply network, its concentration increased in the quarterly cycle. On the other hand, when analyzing the change in chloride content in tap water in the network over the years 2018–2022, it was noticed that for Q1, Q2, and Q3, the amount in tap water increased each year. In Q4, a decrease in chloride concentration was observed, and in 2022, its amount was higher compared to 2021.
- Chromium—Throughout the analyzed period, the average quarterly chromium concentration was in the range of <0.5–<3.0 µg/L. In 2018, 2019, and 2021, the amount of chromium was constantly at the same level of <3.0 µg/L. Slightly different results were observed in 2020, when the amount of detected chromium was abrupt. In 2021, however, a downward trend was observed. To sum up, the chromium content in tap water was characterized by high variability.
- Aluminum—The amount of aluminum in tap water remained at <40.0 µg/L for most of the analyzed period. In some quarters this value is higher, which could be due to irregularities that occurred during treatment, such as in the coagulation process using aluminum compounds. However, increased aluminum concentration in water is sporadic, and always after such an incident, the amount of this element in water decreases.
- Cadmium—When analyzing the results of quarterly average values for cadmium contained in water, it was observed that its concentration remained at a constant level and amounted to <0.5 µg/L.
- Magnesium—Based on the obtained results of analyses of the variability of magnesium content in tap water in the network, a downward trend in the amount of this element in water was observed over the years 2019–2021. The exception is the first quarter of 2019, when the amount of Mg in water was significantly higher than in other quarters. In 2022, a slight increase in Mg in water was observed. The results of the variability of magnesium content in water in the quarterly cycle show, however, that its amount in water fluctuated.
- Manganese—When analyzing the amount of manganese contained in tap water in individual quarters of the five-year study period, it was observed that in 2018–2021, its concentration remained at a constant level of <20 µg/L. The change occurred in the fourth quarter of 2021, when a lower Mn content in water was recorded, and in 2022, its amount remained at a level of <15 µg/L.
- Copper—The results of quarterly water quality analyses for 2018–2022 showed that the concentration of copper was in the range of 0.002–0.005 mg/L. The content of this element in water was characterized by small variability. In 2018 and 2019, the content of this element in water was at the same level, while in 2020 a slight increase was noted. The lowest values were recorded in 2021, when the amount of Cu was 0.002 mg/L. In 2022, its concentration increased again and remained at 0.005 mg/L. Despite small fluctuations, the tap water in the tested network was stable in terms of the copper ions contained in it.
- Nickel—Throughout the analyzed period, the average quarterly concentration of nickel was in the range of <0.5–<6.3 µg/L. The variability of the concentration of this element in tap water was abrupt. The differences in the amount of nickel detected in water could result from the precipitation of this element from water pipes in different amounts.
- Lead—The minimum recorded average quarterly content of lead in water in the water supply network in the analyzed period was <0.5 µg/L, while the highest was <4.3 µg/L. Based on the results of the analyses, it was noted that in most cases, the

average quarterly values were <4.0 µg/L. A noticeable difference was observed in 2020, when a significant decrease in the lead content in the analyzed water was noted.
- Mercury—This parameter has been analyzed since 2019. By analyzing the amount of mercury contained in tap water in individual quarters of the five-year study period, it was observed that its concentration in water remained at a constant level of <0.10 µg/L.
- Sulfates—Throughout the analyzed period, the average quarterly concentration of sulfates was in the range of 29.7–53.0 mg/L. When analyzing the quarterly variability of sulfates in tap water, it was noted that in Q2, the concentration of sulfates was lower than in Q1, and in the subsequent quarters, an upward trend was observed. However, based on the analysis of average quarterly values in the context of changes in the years 2018—2022, a jump in the nature of changes was noted. Despite this, the range of fluctuations in the content of sulfates in water was not large. The exception is Q4 2022, when the recorded concentration of sulfates in water differed significantly from the others. A higher concentration of sulfates in water is associated with an increase in its hardness, due to their combination with calcium and magnesium.
- Total iron—When analyzing the results of quarterly average values for total iron contained in water, it was observed that its concentration remained at a constant level and amounted to <20 µg/L.
- Oxidizability with KMnO4—Throughout the analyzed period, the average quarterly oxidizability was in the range of 0.43–1.50 mg/L. When analyzing the quarterly variability, it was noticed that in the years 2018–2021, in the second and second quarters, oxidizability was lower than in the first quarter. In the fourth quarter, higher value results were recorded than in the previous quarters. An exception was 2022, when an upward trend was observed from the first quarter, and in the fourth quarter, a decrease in oxidizability was noted. On the other hand, based on the analysis of the average quarterly values in the context of changes in the years 2018–2022, a jump in the nature of changes was noticed. The range of fluctuations in water oxidizability was not large. The exception is the third quarter of 2022, when the recorded value differs significantly from the others.
- Chloroform—By analyzing the concentration of chloroform contained in tap water in individual quarters of 2018–2022, it can be observed that its concentration in tap water remained at a constant level and was <1 µg/L.
- Total THM (Trihalomethanes)—Throughout the analyzed period, the average quarterly concentration of total THM was in the range of <1.0–20.7 µg/L. The variability of the concentration of this element in tap water was abrupt. The highest presence of THM was recorded in 2018. In subsequent years, concentrations were lower. Throughout 2022, the total THM present in water was already <1.0 µg/L. Higher THM concentrations in some quarters could have resulted from intensified reactions between chlorine and organic compounds and bromides present in water.
- Total organic carbon (TOC)—Throughout the analyzed period, the average quarterly TOC was in the range of 0.74–2.13 mg/L. Analyzing the quarterly variability, it was noticed that in the years 2018–2021, in the first quarter, the TOC content in water in the water supply network had an upward trend, and then, in 2022, it decreased. In the second quarter, a decrease in the TOC content was noted compared to the first quarter, with the exception of 2019. It was similar in the case of the third quarter, and the only difference was in 2020, when there was an increase. In the fourth quarter, the recorded results were higher than in the third, with the exception of 2019, when the TOC content increased. However, based on the analysis of the average quarterly values in the context of changes in the years 2018–2022, the abrupt nature of the changes can be seen. The range of TOC fluctuations in water was average. An exception was in the third quarter of 2018, when the recorded value was lower and differed from the others.
- Total chlorites and chlorates—Throughout the analyzed period, the average quarterly concentration of total chlorites and chlorates was in the range of <0.15–<0.25 mg/L. The content of chlorites and chlorates was higher in 2018–2020, but a downward trend was

observed later. The higher content of chlorites and chlorates in the water could have been the result of using a larger amount of disinfectant that remained in the water.

- *Escherichia Coli*, *Enterococci*, *Coliform bacteria*, and *Clostridium Perfingens* (with spores)—After analyzing the content of bacteria in water in the water supply network in individual quarters of 2018–2022, no microbiological changes in the tested water were detected. For water hardness, the results of quarterly water quality analyses for the years 2018–2022 showed that water hardness was in the range of 218.7–281.3 mg $CaCO_3$/L. Analyzing the above results, small fluctuations in water hardness were observed for the tested water supply network. Higher value results are observed in 2018–2019 and 2021–2022 for quarter IV. A slight decrease was noted in 2019. Despite small fluctuations, the tap water in the tested network was stable in terms of hardness (water in each analyzed quarter from the period 2018–2022 was classified as medium hardness).

6. Discussion and Conclusions

Drinking microbiologically contaminated water can, of course, have the most negative effects. Many bacteria that may be present in water are responsible for causing digestive disorders and even infectious diseases. Particularly vulnerable groups include infants, children, the elderly, people living in unhygienic conditions, and the chronically ill. Eliminating microbiological contaminants should be given priority over reducing problems caused by chemical contaminants. In the latter case, health problems usually occur as a side-effect of long-term consumption of water of inadequate quality. Special attention should be paid to substances with cumulative toxic properties. These include heavy metals and carcinogens, but also nitrates and nitrites. However, the presence of contaminants in water does not only cause health problems but also leads to a significant deterioration in the functioning of the entire household and minimizes the comfort of using water. Many chemical compounds contribute to the formation of sediments left behind by flowing water. A common problem in households is boiler scale but also precipitated iron and manganese. The phenomenon of sedimentation contributes to the occurrence of failures and premature corrosion, reduction in pipe lumen, reduction in pump and heating efficiency, premature wear of household appliances, and increased costs. Pollutants have a major impact on the organoleptic properties of water. Cloudiness and incorrect color are common problems. The only way to achieve crystal clear and safe water is to analyze its composition. Monitoring water quality is important for a number of reasons. Firstly, it provides a precise knowledge of the parameters of water and the substances it contains. The results of water monitoring provide an accurate list of parameters and their values. This allows for a comprehensive assessment of the type and concentration of pollutants present in the water. Accurate identification of the problem ensures the full possibility of its effective elimination.

The analysis of the averaged results of physicochemical, microbiological, and organoleptic indicators showed that the water in the analyzed water supply network in the years 2018–2022 met the national requirements. The tested water quality would also meet most of the requirements that will be introduced into national law in connection with the need to transpose Directive (EU) 2020/2184 of the European Parliament and of the Council on 16 December 2020 on the quality of water intended for human consumption [1]. The only parameter that would not meet the permissible value is chromium. Its value in each of the analyzed months was <3.0 μg/L, while the new directive tightens the requirements to 0.25 μg/L. The CWSS operator should take action to reduce the amount of chromium in the tap water so that after the introduction of new regulations on the quality of drinking water, the concentration of chromium in the water does not exceed the permissible value.

This is the result of the impact of the general increase in temperature on Earth, which is the result of global warming. Therefore, in the future, there may be a problem of increased development of biofilm in the water supply network, and consequently, the observation of a greater number of bacteria in the water. Despite incidental cases of exceeding the microbiological indicators of water in the water supply network and fluctuations in water quality parameters to a small extent, the water supply water in the network is physically, microbiologically, and chemically stable. The water treatment technologies used by the company and the appropriate management of the water distribution system allow for the supply of water to consumers of the appropriate quality, meeting strictly defined standards and recommendations.

The new water directive sets new tasks for the water sector. One of the challenges will be to adapt water quality monitoring to the new water directive; these changes will concern parametric indicators for lead, a substance disrupting the functioning of the endocrine system (bisphenol-A) and placing beta-estradiol, nonylphenol, and microplastics on the watch list.

Taking into account the recommendations of the new directive regarding the introduction of uniform requirements for materials that may come into contact with water for human consumption, once the Polish regulations adapted to the directive come into force, a review of the materials used should be carried out in the company.

The quality of drinking water in any collective water supply system (CWSS) may change, and various chemical, physical, and biological changes may occur in the system. One of the effective elements influencing the improvement of water quality is the implementation of a hydraulic model, representing the operation of the water supply network. The hydraulic model will allow for modeling of flows and checking of the age of water and therefore will be a tool for monitoring the effects of secondary water contamination in the water supply network. Drinking water testing can serve as an effective management strategy to ensure access to safe tap water, ensure high water quality to support public health improvement, and provide guidance, through water consumer feedback, on where water infrastructure requires renovation or modernization.

There is therefore a justified need for rational water quality management in the CWSS. In order to better understand the need for quality management, it should also be noted that the water supply network, compared to other elements of the CWSS (water intakes, treatment plants, and water reservoirs), has so far been very modestly monitored in terms of water quality, especially in smaller towns and rural units. The water supply network is the last link in the CWSS that delivers it directly to consumers. Therefore, monitoring the water supply network is a key undertaking supporting the proper and sustainable management of the entire CWSS, and the need to conduct continuous research and measurements on the network is one of the main challenges facing water supply companies. In further work, the author plans to focus on the occurrence of microplastic contamination of drinking water and risk analyses related to water quality.

The limitation of the conducted research and analyses is obtaining appropriate agreements and permits for the provision of operational data, due to the fact that the water supply network is part of the critical infrastructure of the state. Critical infrastructure is systems and their functionally related objects that are key to the security of the state and its citizens and serve to ensure the efficient functioning of public administration, as well as institutions and entrepreneurs, and especially water supply systems. The criteria recorded in a classified annex to the National Critical Infrastructure Protection Program (NPOIK) determine whether an object is a critical infrastructure object (CI).

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