Acta Sci. Pol.
Formatio Circumiectus 17 (2) 2018, 57–67
ENVIRONMENTAL PROCESSES

www.formatiocircumiectus.actapol.net/pl/ ISSN 1644-0765 DOI: http://dx.doi.org/10.15576/ASP.FC/2018.17.2.57

ORIGINAL PAPER Accepted: 28.05.2018

WATER TREATMENT IN AN INTEGRATED COAGULATION––MICROFILTRATION SYSTEM, AS ILLUSTRATED WITH THE EXAMPLE OF THE WATER TREATMENT PLANT IN JAROSŁAW

Ewa Dacewicz[1]✉, Mirosław Janowski[2]✉

[1] Department of Sanitary Engineering and Water Management, Faculty of Environmental Engineering and Land Surveying, University of Agriculture in Krakow, al. Mickiewicza 24/28, 30-059 Kraków
[2] Department of Fossil Fuels, Faculty of Geology, Geophysics i Environmental Protecion, AGH University of Science and Technology, al. Mickiewicza 30, 30-059 Kraków

ABSTRACT

The aim of the present work was to assess the functioning of the integrated treatment process of surface water in the Water Treatment Plant (ZUW) in Jarosław between 2008–2015. The application of factor analysis made it possible to reduce the number of random variables down to the set described by four principal components, including two variables related to the bacteriological quality of water. It was observed that the removal of the component bacteria in 2011–2015 (after the modernization of the Water Treatment Plant), during the filtration and disinfection process, was 100% effective. Microfiltration membranes with a nominal pore size of 0.1 μm proved effective in removing both protozoa and pathogenic bacteria from the captured water. The use of the microfiltration technique in the coagulation-integrated system has increased the effectiveness of the conventional disinfection of surface water.

Keywords: water treatment, bacteria, microfiltration, factor analysis

INTRODUCTION

Emission of pollution from municipal wastewater causes the degradation of surface water not only due to the process of its eutrophication, but also due to bacterial contamination. The reason for this is that the sewage going to the rivers constitutes a source of microorganisms, which pose a potential threat to human health. This fact is particularly important in the context of "water security" – suitability of the water, which is captured in order to produce drinking water [Rak 2016].

Epidemiological data indicate that among the diseases in which water may be the cause of infection, the most common are those of the gastrointestinal nature. These can be caused by parasitic protozoa, mainly from the genus of *Giardia* and *Cryptosporidium* [Environment Agency 2010, Atwill et al. 2012, Percival et al. 2014]. This is related to the widespread presence of protozoa in the environment, their high resistance to a variety of living conditions, and to conventional methods of water treatment. *Cryptosporidium* and *Giardia* can survive for several weeks or months in the aquatic environment [Environment Agency 2010, Atwill et al. 2012]. These protozoa are able to survive outside the carrier organism in adverse environmental conditions due to the formation of endospores. *Cryptosporidium* and *Giardia* [Peng et al. 2008] are not, however, an element of quality control of water originating from surface or mixed intakes. Useful indicators of microbial water quality, indicating the presence of these highly resistant protozoa, are *Clostridium per-*

✉e-mail: ewa.wasik@urk.edu.pl, janowski@agh.edu.pl

fringens [Payment and Locas 2011, Atwill et al. 2012]. They are of particular importance, because their endospore forms are similar to cysts/oocysts of parasitic intestinal protozoa, not only due to their similar size, but also due to comparable resistance to disinfectants, and the difficulty to eliminate them by means of conventional water treatment processes [Payment and Locas 2011, Percival et al. 2014].

The most important goal of water treatment intended for consumption is the removal of pathogenic microorganisms and parasites in the number that would pose a potential threat to human health. The presence of Gram-negative (−) bacilli of the *Enterobacteriaceae* family, that is *Escherichia coli*, is a frequently used indicator, testifying to relatively recent water pollution with faeces [Budzińska et al. 2007]. The identification of coliform bacteria from the genus *Klebsiella spp*., *Enterobacter spp*. and *Proteus spp*. provides information not only about faecal contamination, but also about the possible presence in the water of more dangerous pathogenic bacteria of *Salmonella spp*. (causing typhoid fever and paratyphoid fever) or *Shigella spp*. (causing bacterial dysentery). The presence of Gram-positive (+) *cocci* (mainly from the genus of *Enterococcus spp.*) and their resistance to chemical agents are associated with biliary tract infections and gastritis [Szkaradkiewicz 2008]. *Clostridium perfringens* endospores, which can cause food poisoning and wound infections, are able to survive in the aquatic environment for long periods of time. Unlike *E. coli* and other coliforms, they are resistant to temperature and disinfection that applies conventional methods such as chlorination [Bodzek 2013], which is why their presence is evidence of relatively remote water contamination.

Conventional technologies for water treatment are based on the coagulation and disinfection processes using chlorine compounds. As a result of the use of chemical substances, new threats are created in the form of side-products of the disinfectants, which can be harmful to health [Kowal and Świderska-Bróż 2007]. When assessing the effectiveness of conventional surface water treatment technologies, applied in six waterworks in the Podkarpacie region, Matuszewska et al. [2013] did not find presence of protozoa from the genus of *Cryptosporidium* and *Giardia* after the process of coagulation and filtration. In the case of one of the waterworks, both after filtration and after disinfection, there were *Clostridium perfringens*, sulphite-reducing endospores in the amount of 23 CFU/100 cc and 46 CFU/100 cc, respectively. This may suggest the effectiveness of technological processes based, among others, on coagulation, rapid filtration, and disinfection in the removal of parasitic protozoa, in the conditions of low-level contamination of the captured water. In the case of endospores of the anaerobes of the *Clostridium* genus, and at the higher abundance of *Cryptosporidium* and *Giardia* in the surface water (for instance, during the state of flood), the data reported in literature confirm their presence in the water after the full treatment process [Matuszewska et al. 2013].

Therefore, better and more modern solutions should be applied in order to increase health safety. For this reason, interest in low-pressure membrane techniques, i.e. microfiltration (MF) or ultrafiltration (UF), is on the rise. The aforementioned techniques are alternative methods of removing pathogenic bacteria, based on the separation process. UF and MF can increase the efficiency of conventional water disinfection processes due to the fact that the membrane poses a barrier for viruses, bacteria and protozoa of the genus *Giardia* and *Cryptosporidium* [Bodzek 2013]. *Cryptosporidium*'s size is between 5–6 μm, and *Giardia*, 8–10 μm, while the size of protozoa of the *Clostridium spp*. is between 0.3–2.0 μm (in width) up to 1.5–20.0 μm (in length) [Indicators… 2004, Alum et al. 2014, Percival et al. 2014]. The cysts/oocysts are between 3 and 14 μm in size [Ottoson et al. 2006, Bitton 2010, Percival et al. 2014], therefore they are significantly larger than the pore size in MF or UF ultrafiltration microfiltration membranes.

Effective and economically attractive technological systems that apply membranes are used in water treatment plants in the USA (for instance, in Milwaukee) and in Europe (for instance, in France in Vigneux, in Germany in Roentgen, and in Great Britain in Clay Lane) [Chrobot 2015]. Due to the fact that low-pressure membrane processes insufficiently remove organic substances from the water (especially small-molecule fractions), they are often preceded by coagulation or adsorption on active carbon. Such solutions contribute to increasing the efficiency of organic compounds removal from the water, as well as prevent the blocking of membranes (the so-called fouling phenomenon).

In Poland, there are three integrated installations for treating water intended for consumption based on low-pressure membrane processes. One of those is the ZUW (Water Treatment Plant) in Jarosław, located in the San River basin, in the area covered by the "Blue San River" Program [Prognoza... 2014].

The aim of the present paper was to evaluate the functioning of the integrated coagulation-microfiltration system in the Water Treatment Plan in Jarosław, in the years 2008–2015. In order to assess the efficacy over a period of many years, the source data was first subjected to a multidimensional statistical analysis. The latter is applied in order to determine the relationship between multiple source data, and to identify the factors that are common to that data. For its implementation, we can use either the principal components analysis [Bedla and Król 2014, Wąsik et al. 2017] or the factor analysis, reducing the number of random variables by identifying structures within their set [Morrison 1990].

DESCRIPTION OF THE STUDIED OBJECT

The water supply network in Jarosław is located along the main communication routes, i.e. roads. Due to its territorial range, it is included in the central system, which is supplying water not only to the city of Jarosław, but also to the surrounding villages (see: Figure 1).

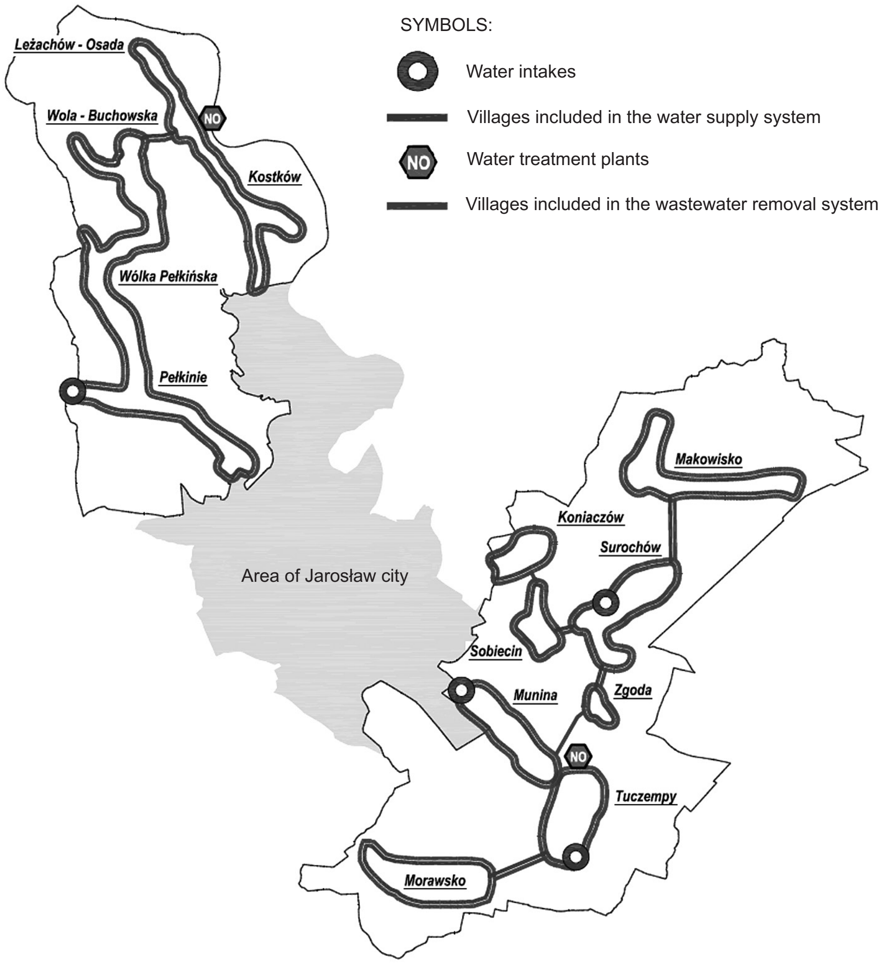
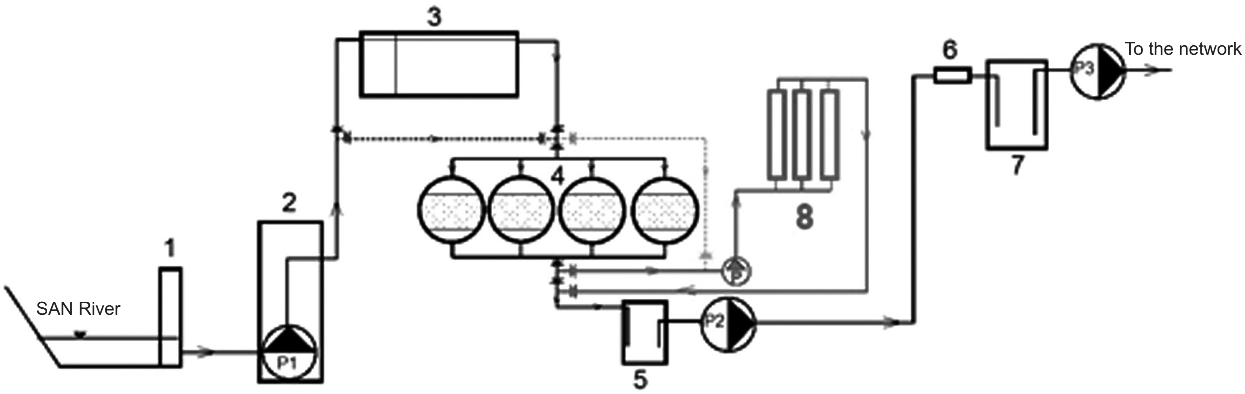


Fig. 1. Diagram of the situational plan of collective water supply system in Jarosław [source: http://jaroslaw.itl.pl/bip/atach/4/2067/4788/8.%20System%20zaopatrzenie%20w%20wode%20i%20odprowadzania%20sciekow%20-%20schemat.pdf]

The Jarosław Water Treatment Plant, with a maximum capacity of 27380 cubic metres per day, and a daily average capacity of 11280 cubic metres, supplies the city's water network from a surface intake (the San River) and from underground water intakes (Garbarze–Szówsko – deep water wells, and Pawłosiów – deep water wells). The surface water is captured in Munin by means of the shore intake, and then it gravitationally flows into the collecting well, whence it is pressed into the coagulation unit (ZUW Górny – Upper Water Treatment Plant). This is followed by the stage of dosing the coagulant (PAX-16 polyaluminium chloride) into the raw water, then the coagulation process, and finally the separation and retention of a significant part of the suspension in the sludge chambers. The water from the post-coagulum chambers flows down gravitationally to the filtration units of the ZUW-Dolny (the Lower Water Treatment Plant). After the filtration process on sand, gravel and diaphragm filters, the water flows into the clean water collecting well, whence it is pressed into the ZUW Górny (the Upper Treatment Plant). Clean water disinfection takes place with the application of chlorine dioxide [Satora 2005, Satora et al. 2009].

Until 2009, the Water Treatment Plant relied on traditional technology for drinking water treatment: coagulation, horizontal pressure sand filtration, and disinfection using gas chlorination. The appearance of *Clostridium perfringens* was a direct cause of the modernization of the filtration and disinfection system (see: Figure 2). The installation of membrane filters was commissioned in 2010, and a year later, the disinfection method was changed from chlorine gas to chlorine dioxide [Program... 2012].

The membrane filter system consists of 120 Pall Microza modules. They were installed in three blocks of 40 filtration modules each. The single module consists of 6000 polymer membranes of hollow-fibre PVDF type [PWiK Jarosław... 2009]. The nominal pore diameter of the applied microfiltration membrane is 0.1 μm, and the flow of filtered water takes place from the outside towards the inside of the membrane [Pall Hollow Fibre... 2018]. In February 2012, a failure of the membrane filters occurred. The reason for that was the very low water level in the San River at the time, coupled with sub-zero temperatures. Due to the drop in the efficiency of filters, the Water Treatment Plant was not able to provide the right amount of water to the places located furthest away from the facility. It was then decided that a further design solution should be adopted, namely the installation of an ultraviolet radiation reactor [Polnik... 2017].



1 – Shore intake
2 – Raw water well with first degree pumps (P1)
3 – Coagulation with post-coagulum chambers (4 lines)
4 – Horizontal pressure sand filters
5 – Filtered water collecting well
P2 – Filtered water pumps
6 – Water disinfection using gas chlorination
7 – Clean water collecting well
P3 – Clean water pumps
8 – Membrane filters installation

Fig. 2. Simplified scheme of the Water Treatment Plant in Jarosław [source: http://bip105.lo.pl/?cid=186]

RESEARCH METHODOLOGY

A set of the results obtained during the two years before the modernization of the facility (from January 2008 to December 2009), and then five years after its modernization (from January 2011 to December 2015), has been subjected to analysis. Due to the lack of data, the year 2010 was not included in the study. The test results on the quality of raw water (taken from the San River) and on the treated water (before its introduction into the municipal water supply system), carried out by an accredited laboratory, were obtained from the PWiK in Jarosław [Polnik 2017]. The physical factors (i.e. turbidity, colour, reaction), the chemical factors (i.e. general hardness, content of manganese, general iron, and ammonium nitrogen), and the bacteriological factors (i.e. the total number of mesophilic and psychrophilic bacteria, coliform bacteria, *Escherichia coli*, *Enterococcus faecalis*, and *Clostridium perfringens*) were determined in accordance with the standards as per the regulations at the time of testing [Polnik 2017].

In order to assess efficacy over the period of 2008–2015, the source data was subjected to factor analysis. Keiser's value criterion was used to select the number of factors chosen to determine the structure, within the set of thirteen factors [Morrison 1990, StatSoft 2018]. The groups thus defined served as input variables used in the evaluation of the membrane system functioning, preceded by a coagulation process. The values of the selected factors of conditioned water have been presented in the form of box-plot charts.

The final stage consisted in the analysis of variance performed on the source data, aimed at comparing the differences between individual factors over the period of 2008-2015. This required preliminary determination of the normality of the distribution of variables, which was conducted using the Shapiro-Wilk test. The homogeneity analysis of variance using the Levene test was applied in order to check the significant differences between the variances of the removed contaminations. In order to demonstrate between which groups the rank differences were the most significant, the non-parametric Kruskal-Wallis test was carried out at the significance level of $p < 0.05$.

The statistical analysis was carried out with the aid of the Statistica 12.5 software.

RESEARCH RESULTS

According to the WIOŚ Rzeszów report [Jakość wód… 2012] at the measurement and control points in Ostrów (above Przemyśl town – uniform body of water of the San River from Olszanka to Wiar), and in Radymno (above Jarosław town – uniform body of water of the San River from Huczki to Wisłok, minus the Wisłok River), it was found that the waters of the San River did not correspond to any of the permissible quality categories. The main factor that disqualified the monitored waters was their bacteriological pollution, characterized most often by the number of coliform bacteria and the faecal coliform group. The average number of bacteria in the water from the San River during the analysed period amounted to: for coliform bacteria, $1.4 \cdot 10^3$ CFU/100 ml; for *Escherichia coli*, $2.9 \cdot 10^2$ CFU/100 ml; for *Enterococcus faecalis*, $3.2 \cdot 10^2$ CFU/100 ml; and for *Clostridium perfringens*, $3.5 \cdot 10^2$ CFU/100 ml.

The integrated coagulation-membrane filtration process used in the ZUW Jarosław Water Treatment Plant was aimed at improving the quality of water in terms of its physical factors (turbidity, colour, pH), its chemical factors (general hardness, content of manganese, general iron, ammonium nitrogen), and its bacteriological factors (total number of mesophilic and psychrophilic bacteria, coliforms, *Escherichia coli*, *Enterococcus faecalis*, and *Clostridium perfringens*).

Factor analysis made it possible to reduce the number of random variables down to the set described by four factors (see: Table 1).

Table 1. Factor analysis: principal component method

Factor	Own value	% of total variance	Accumulated own value	Accumulated %
F1	2.165353	19.68	2.165353	19.68
F2	1.805919	16.42	3.971272	36.10
F3	1.677818	15.25	5.649089	51.35
F4	1.408378	12.80	7.057467	64.16

The application of the factor axis rotation strategy of normalized Equamax (see: Table 2) yielded a simpler factor load structure, as shown in Figure 1. It was found that the first factor, F1, describing 19.68% of

Table 2. Factor load values after normalized Equamax rotation

Variable	F1 factor	F2 factor	F3 factor	F4 factor
Turbidity	0.191311	–0.063373	0.101724	**0.859197**
pH	0.556143	0.225327	0.029873	–0.242903
General hardness	0.575300	–0.240542	0.137497	0.250626
Mn	0.109793	**–0.904676**	–0.078405	–0.109701
Fe	–0.077325	**–0.904561**	0.082238	0.122877
NO_3^-	0.573783	0.120223	–0.207566	0.265417
NH_4^+	**0.753613**	–0.191709	0.063842	0.074668
Permanganate index	0.375200	0.172166	0.157745	–0.406078
NPL 36º	0.001710	0.001600	**0.922658**	–0.005077
NPL 22º	0.095401	–0.006094	**0.907509**	0.045990
Clostridium perfingens	0.078031	0.093567	0.010361	**0.741736**

Load values in bold are > 0.700000

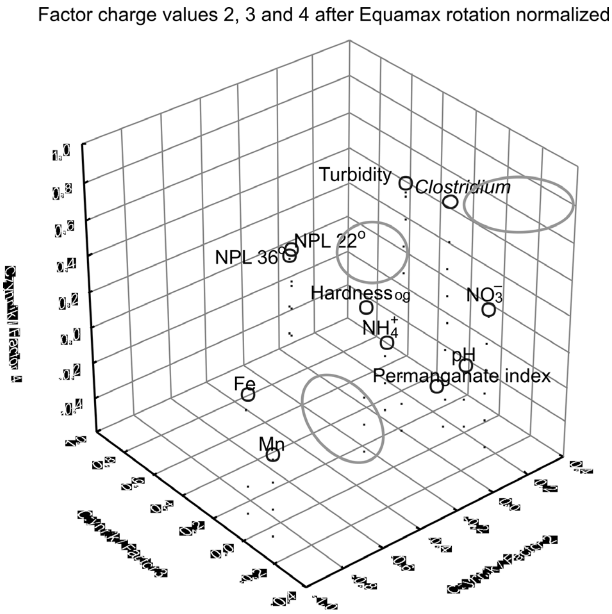


Fig. 3. Factor charges 2–4 (marked with an ellipse) with normalized Equamax factor axis rotation

the total variability stock, was explained by the variable of ammonium ion. The second factor, F2, representing 36.1% of the total volatility, was primarily related to the variables of manganese and iron. The third and fourth factors, F3 and F4, covering respectively 51.35% and 64.16% of the total volatility stock, were identified with the content of mesophilic (NPL 36º) and psychrophilic (NPL 22º) bacteria, and *Clostridium perfringens* respectively (see: Figure 3).

The results of the values of selected factors, determined in the water samples tested over the period of 2008–2015, are presented graphically below, in the form of box-plot charts.

Figure 4a shows turbidity changes in the analysed multi-year period. In 2008 and 2009, the water, having passed through pressure filters, had an average turbidity of 0.44 NTU and 0.32 NTU, respectively. With the average turbidity of recorded water amounting to 39.1 NTU, a decrease in this index value of over 90% was achieved in the filtration process. Turbidity affects the appearance, and indirectly also the taste of water [Pawełek and Bergel 2009], and it is an indicator of the on-going control of the efficiency of the filtration process [Bergel and Kudlik 2009]. In the analysed period, after the modernization of the facility, smaller turbidity ranges of water filtered through membrane modules were observed. The median value over time has almost doubled – from 0.2 NTU (2011) to 0.12 NTU (2015). This allows us to conclude that in terms of this parameter, throughout the entire long-term period, the water fulfilled the requirements of the then-binding Regulation by the Minister of Health [Rozporządzenie… 2015].

Iron compounds present in the water can affect its turbidity and colour. As a result of microfiltration, a slight decrease in the average value of this parameter was observed (see: Figure 4b). The median of this factor in the treated water decreased on average from 0.04 down to 0.01 mgFe · dm^{-3} (efficiency 95.8%), that is below the permissible limit value of 0.2 mgFe · dm^{-3} [Regulation ... 2015]. The only observed exceedance of this value, up to the level of 0.8 $mgFe_{og}$ · dm^{-3}, was observed in April of 2009. In the years covered by the study, ammoniacal nitrogen was removed with an average efficiency of 43%, while the median value in the treated water oscillated at a similar level of 0.03––0.04 mg of N-NH_4^+ · dm^{-3} (see: Figure 4c).

Bacterial content found at 22°C (i.e. psychrophilic bacteria) is composed mostly of those microorganisms that occur naturally in water and soil. It is assumed

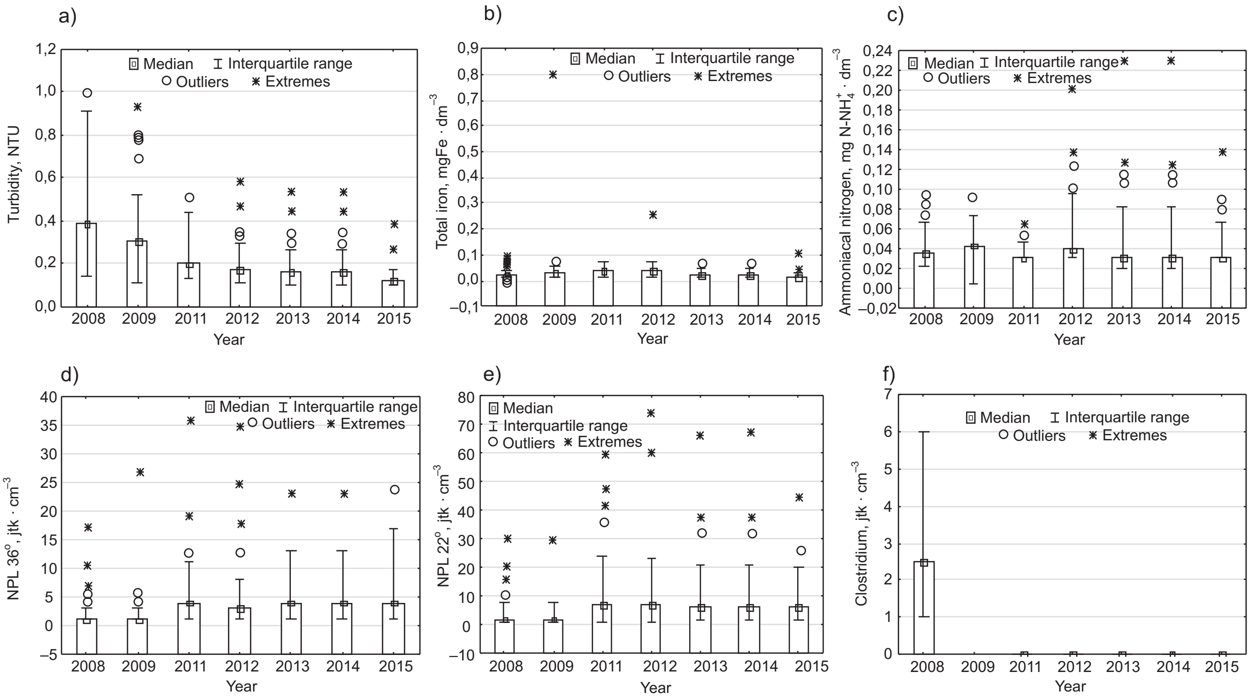


Fig. 4. Box-plot diagrams of turbidity (a), total iron (b), ammoniacal nitrogen (c), total number of mesophilic bacteria (d), total number of psychrophilic bacteria (e), *Clostridium perfringens* (f)

that in the case of their numerous presence, they can be an indicator of organic pollution. These bacteria develop on filters in the form of the so-called biological membrane. Having penetrated through the filters to the water supply network, they can multiply there, negatively affecting the biological stability of tap water. In turn, the increased amount of bacterial content determined at 36°C (i.e. mesophilic bacteria) is more dangerous in terms of health considerations, because this may include pathogenic bacteria. In the years covered by the study, the mesophilic and psychrophilic bacteria were removed with very high efficiency (on average, at the level of 99.8%). The median value in the treated water fluctuated between 1 and 4 CFU per 100ml and between 2 and 7 CFU per 100ml, respectively (see: Figures 4d and 4e), which means that it did not exceed the permissible values for psychrophilic bacteria (< 100 cells per 1 ml) or for mesophilic bacteria (< 50 cells per 1 ml) [Regulation ... 2015].

As demonstrated by the results of the testing conducted in 2008, that is in the period before the modernization of the facility, in samples obtained of the water collected after passing through the pressure sand filters, an over-normal content of disinfectant resistant, anaerobic bacteria of *Clostridium perfringens* was found, in the amount of 1-6 CFU / 100 ml (see: Figure 4f). According to the regulations in force in Poland, 100 ml of the water intended for consumption must not contain any cells of bacteria considered as indicators. As expected, in the years following the introduction of the microfiltration system, 100% removal of *Clostridium perfringens* endospores was achieved in the production line. In the case of the remaining three indicator microorganisms, the presence of these bacteria was not found in the analysed samples.

The final stage of the study was the analysis of variance applied to two groups of source data, that is physicochemical indicators (turbidity), and bacteriological indicators (*Clostridium perfringens*, mesophilic and psychrophilic), which determined the sanitary quality of the treated water. The Shapiro-Wilk test confirmed the lack of normal distribution for the aforementioned parameters. The homogeneity analysis of variance using the Levene test showed the existence of differences between the variances of the analysed indicators of the treated water in the period of 2008–2015. As shown in Tables 3 and 4, in the case of turbidity, and in the case of *Clostridium perfringens*, it was the years 2011–2015 that were responsible for the negative result of the Kruskal-Wallis test, which means that they were statistically different from the years before the modernization of the Water Treatment Plant (ZUW).

When analysing the post-hoc test results for mesophilic bacteria (see: Table 5) and psychrophilic bacteria (see: Table 6), we have found statistically significant differences at the level of significance of <0.05, between the year 2009 and the remaining years after the introduction of membrane filtration.

Table 3. Post-hoc test results for turbidity

Year	Turbidity; Kruskal-Wallis test: H (6, N = 399) = 176.6979 p = 0.000						
	2008	2009	2011	2012	2013	2014	2015
2008		2.768255	**4.451504**	**6.615734**	**7.990132**	**7.990132**	**11.50388**
2009	2.76825		1.636610	**3.847246**	**5.261278**	**5.261278**	**8.84978**
2011	**4.45150**	1.636610		2.282462	**3.748138**	**3.748138**	**7.45227**
2012	**6.61573**	**3.847246**	2.282462		1.475286	1.475286	**5.17942**
2013	**7.99013**	**5.261278**	**3.748138**	1.475286		0.000000	**3.68866**
2014	**7.99013**	**5.261278**	**3.748138**	1.475286	0.000000		**3.68866**
2015	**11.50388**	**8.849779**	**7.452268**	**5.179417**	**3.688664**	**3.688664**	

Table 4. Post-hoc test results for *Clostridium perfringens*

Year	*Clostridium perfringens*; Kruskal-Wallis test: H (6, N = 300) = 0.000000 p = 1.000						
	2008	2009	2011	2012	2013	2014	2015
2008		–	4.038474	4.035366	4.032159	4.032159	**4.035366**
2009	–		–	–	–	–	–
2011	**4.038474**	–		0.000000	0.000000	0.000000	0.000000
2012	4.035366	–	0.000000		0.000000	0.000000	0,000000
2013	**4.032159**	–	0.000000	0.000000		0.000000	0.000000
2014	**4.032159**	–	0.000000	0.000000	0.000000		0.000000
2015	**4.035366**	–	0.000000	0.000000	0.000000	0.000000	

Table 5. Post-hoc test results for the total number of mesophilic bacteria (NPL 36°)

Year	NPL 36°; Kruskal-Wallis test: H (6, N = 375) =94.79280 p = 0.0000						
	2008	2009	2011	2012	2013	2014	2015
2008		0.630099	**4.566184**	**4.381634**	**5.729852**	**5.729852**	**5.999825**
2009	0.630099		5.256579	5.070933	6.421227	**6.421227**	**6.701613**
2011	**4.566184**	**5.256579**		0.195271	1.268821	1.268821	1.498915
2012	**4.381634**	**5.070933**	0.195271		1.462340	1.462340	1.695033
2013	**5.729852**	**6.421227**	1.268821	1.462340		0.000000	0.211130
2014	**5.729852**	**6.421227**	1.268821	1.462340	0.000000		0.211130
2015	**5.999825**	**6.701613**	1.498915	1.695033	0.211130	0.211130	

Table 6. Post-hoc test results for the total number of psychrophilic bacteria (NPL 22°)

Year	NPL 22°; Kruskal-Wallis test: H (6, N = 380) = 90,22070 p = 0.0000						
	2008	2009	2011	2012	2013	2014	2015
2008		0.966215	**5.096080**	**5.150597**	**5.460520**	**5.460520**	**4.338250**
2009	0.966215		**6.139113**	**6.202500**	**6.510038**	**6.510038**	**5.389383**
2011	**5.096080**	**6.139113**		0.015201	0.362539	0.362539	0.861656
2012	**5.150597**	**6.202500**	0.015201		0.350464	0.350464	0.884782
2013	**5.460520**	**6.510038**	0.362539	0.350464		0.000000	1.232839
2014	**5.460520**	**6.510038**	0.362539	0.350464	0.000000		1.232839
2015	**4.338250**	**5.389383**	0.861656	0.884782	1.232839	1.232839	

CONCLUSIONS

In the present paper, we have demonstrated that in the period of 2011–2015, the use of an integrated coagulation-microfiltration system made it possible to remove suspended particles and colloidal fraction present in the captured water, and to obtain water with turbidity in accordance with the requirements. Microfiltration membranes with a nominal pore size of 0.1 µm were found to be 100% effective in removing protozoa and pathogenic bacteria from the water.

Factor analysis facilitated the reduction from among of 13 random variables down to a set described by four main factors, including two factors related to bacteriological indicators. The results we have obtained from the analysis of variance indicate the existence of clear differences between 2008 and 2009, and the remaining years after the introduction of membrane filtration.

According to the results of the water quality tests obtained in the Jarosław ZUW Water Treatment Plant, the latter meets the acceptable quality standards defined by the Regulation of the Minister of Health of November 13, 2015 on the quality of water intended for consumption [Regulation ... 2015]. The tested water in the period after the introduction of microfiltration, applying Pall Microza modules on the capillary membranes, corresponded to the organoleptic, physicochemical and microbiological requirements of the aforementioned regulation. It is worth emphasizing that the removal of indicator microorganisms by means of highly efficient membrane filtration is a cost-effective and efficient method, the application of which guarantees constant quality of the water thus produced, as well as easy expansion of the scale and automation of the process.

Another important factor is the operating cost of the installation, because this directly affects the price per one cubic meter of the water produced. Membrane technology is more expensive than the classic technology at the investment stage, mainly due to the cost of the membrane modules. Considering the operating costs, however, it is the membrane technology that is cheaper, especially in terms of water consumption for rinsing, energy consumption for water production, and a significant reduction in the use of disinfectant [Bodzek 2013, Makowska and Krauze 2017].

LITERATURE

Alum, A., Absar, I, Asaad, H., Rubino, J.R., Jaz, M.K. (2014). Impact of Environmental Conditions on the Survival of *Cryptosporidium* and *Giardia* on Environmental Surfaces Hindawi Publishing Corporation, Interdisciplinary Perspectives on Infectious Diseases, Volume 2014, 0-7, http://dx.doi.org/10.1155/2014/210385

Atwill, E.R., Partyka, M.L., Bond, R.F., Li, X., Xiao, C., Karle, B. (2012). Introduction to Waterborne Pathogens in Agricultural Watersheds. United States Department of Agriculture, Natural Resources Conservation Service. Nutrient Management Technical Note No. 9.

Bedla, D., Król, K. (2014). Wpływ użytkowania zlewni na jakość wód stawu wiejskiego na przykładzie zbiornika Zelków. Acta Sci. Pol., Formatio Circumiectus, 13(4), 25–33.

Bergel, T., Kudlik, K. (2011). Fizyczno-chemiczna i bakteriologiczna skuteczność filtrów DynaSand w zakładzie oczyszczania wody zaopatrującym Nowy Sącz. Ochrona Środowiska 4/2011, s. 57–61.

Biłozor, S. (2015). Uzdatnianie wody w procesach membranowych. Magazyn Instalatora, Woda i Kanalizacja. http://www.instalator.pl/2015/10/uzdatnianie-wody-w-procesach-membranowych/ [dostęp: 05.01.2018].

Bitton, G. (2010). *Wastewater Microbiology*, 4th ed.; Wiley-Blackwell: Hoboken, NJ, USA.

Bodzek, M. (2013). Przegląd możliwości wykorzystania technik membranowych w usuwaniu mikroorganizmów i zanieczyszczeń organicznych ze środowiska wodnego. Inżynieria i Ochrona Środowiska 16.

Budzińska, K., Berleć, K., Traczykowski, A., Pawlak, P. (2007). Ocena skuteczności usuwania zanieczyszczeń mikrobiologicznych ze ścieków z zastosowaniem drenażu rozsączającego. Zeszyty Naukowe Wydziału Budownictwa i Inżynierii Środowiska/Politechnika Koszalińska, 623–633.

Chrobot, P. (2015). Potencjał technologii membramowych w branzy wod-kan. Wodociągi – Kanalizacja, 10, http://e-czytelnia.abrys.pl/wodociagi-kanalizacja/2015-10-879/raport-wod-kan-10370/potencjal-technologii-membranowych-w-branzy-wod-kan-20677 [dostęp: 05.01.2018].

Environment Agency (2010). The Microbiology of Drinking Water. Part 14 - Methods for the isolation, identification and enumeration of *Cryptosporidium* oocysts and *Giardia* cysts, http://www.environment-agency.gov.uk/static/documents/Research/Part_14-oct20-234.pdf

Indicators…2004. Indicators for Waterborne Pathogens Committee on Indicators for Waterborne Pathogens, National Research Council 2004 http://www.nap.edu/catalog/11010.html [dostęp: 05.01.2018].

Jakość wód…2012. Jakość wód powierzchniowych wykorzystywanych do zaopatrzenia ludności w wodę przeznaczoną do spożycia w województwie podkarpackim wg badań wykonanych w latach 2007–2011, https://wios.rzeszow.pl/cms/upload/edit/file/opracowania/ jakosc_wod/JAKOSC_WOD_ZAOPATRZENIE_W_WODE_2007-2011.pdf

Kowal, A.L., Świderska-Bróż, M. (2007). Oczyszczanie wody. PWN , Warszawa.

Makowska, M., Krauze, J. (2017). Filtration or separation – comparative cost analysis for underground water treatment system. Acta Sci.Pol. Form. Cir. 16(4), 155-166. http://dx.doi.org/10.15576/ASP.FC/2017.16.4.155

Matuszewska, R., Szczotko, M., Giziński, R., Krogulska, B. (2013). Ocena skuteczności procesów oczyszczania wód powierzchniowych ujmowanych w województwie podkarpackim na podstawie występowania pierwotniaków z rodzaju *Cryptosporidium i Giardia* oraz klostridiów redukujących siarczyny. Ochrona Środowiska, 35(3), 49–52.

Morrison, D.F. (1990). Wielowymiarowa analiza statystyczna. PWN, Warszawa.

Ottoson, J., Hansen, A., Westrell, T., Johansen, K., Norder, H, Stenström, T.A. (2006). Removal of noro- and enteroviruses, *Giardia* cysts, *Cryptosporidium* oocysts, and fecal indicators at four secondary wastewater treatment plants in Sweden. Water Environ. Res. 78, 828–834.

Pall Hollow Fiber…2018. http://www.pall.fr/pdfs/mapped/WP-1d_Hollow_Fiber_Data.pdf [dostęp: 05.01.2018].

Pawełek, J., Bergel, T. (2009). Ocena jakości wody do spożycia dostarczanej przez wodociągi wybranego powiatu województwa małopolskiego. Infrastruktura i Ekologia. Terenów Wiejskich, PAN Kraków, 9(29), 165-172.

Payment, P., Locas, A. (2011). Pathogens in Water: Value and Limits of Correlation with Microbial Indicators, 49(1), Ground Water, 4–11, doi: 10.1111/j.1745-6584.2010.00710.x

Peng, X., Murphy, T., Holden, N.M. (2008). Evaluation of the effect of temperature on the die-off rate for *Cryptosporidium parvum* oocysts in water, soils, and feces. Appl. Environ. Microbiol. 74(23), 7101–7107, doi: 10.1128/AEM.01442-08

Percival, S.L, Marylynn, V., Yates, D., Williams, R., Chalmers, N., Gray. (2014). Microbiology of Waterborne Diseases: Microbiological Aspects and Risks. Second edition, Academic Press, London, 2014, 1–696

Polnik, K. (2017). Analiza nowego rozwiązania w technologii uzdatniania wody na przykładzie ZUW Jarosław. Praca magisterska pod kierunkiem dr inż. Ewy Wąsik, UR w Krakowie, Kraków (manuskrypt).

Prognoza…2014, Prognoza oddziaływania na środowisko projektu Programu Strategicznego Błękitny San, https://www.podkarpackie.pl/attachments/article/3218/ [dostęp: 05.01.2018].

Program…2012. Program ochrony środowiska dla Miasta Jarosławia – aktualizacja. *bip.jaroslaw.um.gov.pl/bip_download.php?id=22781*

PWiK Jarosław…2009. http://bip105.lo.pl/?cid=187 [dostęp: 05.01.2018].

Rak, J.R. (2016). Rozważania na temat bezpieczeństwa wodnego i bezpiecznej wody, GWiTS 2016/4, DOI:10.15199/17.2016.4.6

Rozporządzenie…, 2015. Rozporządzenie Ministra Zdrowia z dnia 13 listopada 2015 r. w sprawie jakości wody przeznaczonej do spożycia. (Dz.U. 2015 poz. 1989).

Satora, S. (2005). Wykorzystanie wód rzeki San dla potrzeb miasta Jarosław. II Konferencja Naukowo-Techniczna „Błękitny San” Ochrona środowiska, walory przyrodnicze i rozwój turystyki w dolinie Sanu, Dynów, 189–209.

Satora, S., Chmielowski, K., Milijanovic, E. (2009). Wykorzystanie wód rzeki San do zaopatrzenia w wodę do celów komunalnych wybranych aglomeracji miejskich. Infrastruktura i Ekologia Terenów Wiejskich (06).

StatSoft…2018. Internetowy Podręcznik Statystyki PL. Kraków http://www.statsoft.pl/textbook/stathome.html [dostęp: 05.01.2018].

Szkaradkiewicz, A. (2008). Antybiotykoterapia w ciężkich zakażeniach wewnątrzbrzusznych. Zakażenia, Tom: T. 8 nr 6, 21-25.

Wąsik, E., Chmielowski, K., Operacz, A. (2017). PCA jako narzędzie eksploracji danych charakteryzujących pracę komór nitryfikacji oczyszczalni ścieków w Trepczy. Acta Sci. Pol., Formatio Circumiectus, 16(1), 209–222.

UZDATNIANIE WODY W ZINTEGROWANYM UKŁADZIE KOAGULACJA – MIKROFILTRACJA NA PRZYKŁADZIE ZAKŁADU UZDATNIANIA WODY W JAROSŁAWIU

ABSTRAKT

Celem pracy była ocena funkcjonowania zintegrowanego procesu uzdatniania wody powierzchniowej w ZUW Jarosław w latach 2008-2015. Wykorzystanie analizy czynnikowej pozwoliło na zredukowanie liczby zmiennych losowych do zbioru opisywanego przez cztery główne czynniki, w tym dwa związane z jakością bakteriologiczną wody. Zaobserwowano, że usuwanie bakterii wskaźnikowych w latach 2011–2015 (po modernizacji ZUW) w procesie filtracji i dezynfekcji przebiegało ze stuprocentową efektywnością. Membrany mikrofiltracyjne o nominalnej średnicy porów 0,1 µm okazały się skuteczne pod względem usunięcia z ujmowanej wody zarówno pierwotniaków, jak i komórek bakterii chorobotwórczych. Zastosowanie techniki mikrofiltracji w układzie zintegrowanym z koagulacją zwiększyło efektywność dotychczas stosowanego konwencjonalnego procesu dezynfekcji wody powierzchniowej.

Słowa kluczowe: uzdatnianie wody, bakterie, mikrofiltracja, analiza czynnikowa