J. Elem. s. 149–159
DOI: 10.5601/jelem.2013.18.4.541

DO WATER FILTERS IMPROVE THE QUALITY OF POTABLE WATER?

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Abstract

It is common knowledge that household water filtration systems cause water demineralisation. However, the available literature lacks data concerning to what extent filters decrease concentrations of chosen mineral components in water. The aim of the study was to estimate the effect of filters mounted on domestic water intakes on the changes in selected water properties. Water samples filtered in a reverse osmosis system and not enriched by further mineralization were taken for the study. Total hardness, concentrations of magnesium, calcium, chloride and nitrate ions and water pH and conductivity were determined after filtration and compared with the same parameters in water from the waterworks. Randomly chosen water samples used for the study were taken from sites in north-eastern Poland. The analyses were carried out according to current standards. All the studied samples of unfiltered water met the drinking-water quality standards laid down by the Regulation of the Minister of Health. In the study, it was demonstrated that water filters significantly decreased electrolytic conductivity as well as the concentrations of magnesium and calcium ions (decisive for water hardness) and chlorides. The analysed filters also increased water acidity. Drinking filtered water decreases the share of water in the recommended dietary allowance (RDA) for calcium and magnesium and may result in many diseases, which is discussed in the paper. No positive effect of water filters on nitrate concentrations was found. The authors proved that installing household water treatment devices seems unnecessary, especially when water is purchased from municipal waterworks and tested as safe for human consumption.

Key words: unfiltered water, filtered water, total hardness, magnesium, calcium, chlorides, nitrates, electrolytic conductivity, water pH.

INTRODUCTION

Assessment of potable water quality is standardised in Poland by the Regulation of the Minister of Health of 29 March 2007 on the requirements pertaining to the quality of potable water (*Regulation*... 2007 with subsequent amendments *Regulation*... 2010). The document takes into account

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the recommendations given in the Council Directive 98/83 EC on the quality of water intended for human consumption. It contains i.a. strictly defined chemical requirements which potable water should conform to. Total hardness, concentrations of magnesium, chlorides and nitrates and electrolytic conductivity and pH are among standardised chemical indices.

Total hardness is determined by the content of divalent cations, mainly by calcium and magnesium. Both are considered macroelements. Calcium and magnesium are indispensable components of human diet – they both participate in many physiological processes in the human organism at subcellular, cellular and tissue levels. Their deficit or excess leads to hypocalcemia and hypomagnesemia, respectively (Kołłątaj, Szewczyk 2006, Pasternak et al. 2010, Grzebisz 2011, Błaszczyk, Duda-Chodak 2013).

Magnesium activates over 300 enzymatic reactions. It participates in the transformation of proteins, lipids, nucleic acids; magnesium is also an activator of enzymes associated with the transfer of phosphate groups, it participates in reactions with ATP, in nucleic DNA transcription, in translation of mRNA in ribosomes and finally it stabilises cell membranes. The Recommended Dietary Allowance (RDA) for magnesium is 300 - 350 mg for adults, being even higher for children and adolescents, breastfeeding and pregnant women and persons exposed to stress or intensively exercising (Knypl 2005, Pasternak et al. 2010, Grzebisz 2011, Błaszczyk, Duda-Chodak 2013).

Calcium is the basic component of bone structure. It plays an important role in the contraction of smooth, skeletal and heart muscles, participates in blood coagulation, affects the synthesis and release of antibodies, the synthesis of structural and regulatory proteins and release of some hormones (e.g. insulin) (Kołłątaj, Szewczyk 2006). The Recommended Dietary Allowance (RDA) of calcium for adult humans is 1000 mg (Januszko et al. 2012).

Daily supply of calcium and magnesium with drinking water should constitute at least 15% of the RDA. The ratio of Ca^{2+} to Mg^{2+} ions is also important. The molar Ca to Mg ratio equal 2 ensures optimum assimilation of both elements by the human body (Wojtaszek 2006).

The presence of chlorides, mainly as NaCl, in food maintains proper osmotic pressure in cells. Chlorides are the main component of digestive acids in the stomach. They maintain acid-base equilibrium and activate some enzymes,like amylase. Chloride ions are ingested in the form of salts, mainly as NaCl. The recommended daily NaCl consumption is 3-6 g (Suliburska 2010).

Nitrates are undesirable in excessive amounts in natural water. In the human alimentary tract, they are easily reduced to nitrites, which cause methemoglobinemy (the so-called "blue baby syndrome") and hypertension, increased infant mortality, diabetes, central nervous system birth defects, spontaneous abortions, respiratory tract infections and changes in the immune system (Fewtrell 2004). The presence of nitrates in human diet may result in the formation of N-nitrozo compounds, many of which are cancerogenic (Nowak, Libudzisz 2008). The Joint FAO/WHO Expert Committee on

Food Additives (JECFA 2003) and Commission Regulation (*Commission* ... 2011) established the Acceptable Daily Intake (ADI) of nitrates at 0-3.7 mg kg^{-1} body weight.

The Regulation of the Minister of Health on the quality of water intended for human consumption (*Regulation* ... 2007) imposes an obligation on the State Sanitary Inspection to issue regional assessments of water quality and to estimate health risk of consumers. The content of nitrates in drinking water should not exceed 50 mg dm^{-3}, concentrations of chlorides should be less than 250 mg dm^{-3}, total hardness – 60-500 mg $CaCO_3$ dm^{-3}, concentration of magnesium 30-125 mg dm^{-3}, electrolytic conductivity should not exceed 2500 mS cm^{-1} and pH 6.5-9.5. The calcium concentration in drinking water is not limited but its content determines water hardness and concentrations of calcium and magnesium in waters are significantly and positively correlated (Czekała et al. 2011).

Water filters have recently been often installed in many households to improve the quality of water intended for consumption. Filter producers asssure their clients that they will have water of excellent quality (Derkowska-Sitarz, Adamczyk-Lorenc 2008). Some studies (Drobnik 2002, Drobnik, Latour 2005, Derkowska-Sitarz, Adamczyk 2008) underlined that the consumption of demineralized water may disturb the electrolytic equilibrium in an organism and exert negative effects on consumers' health. There is no information, however, to what extent filters decrease concentrations of selected ions in water.

Analyses undertaken within this study were aimed at estimating the effect of water filters on chemical properties of drinking water, with a specific focus on the indices like total hardness, concentrations of magnesium, calcium, chlorides, nitrates and water pH and electrolytic conductivity.

MATERIAL AND METHODS

Water samples were taken at random from 13 localities. In 10 sampling sites (1 – Biała Podlaska, 2 – Ełk, 3 – Hajnówka, 4 – Harachwosty, 5 – Korczew, 6 – Ozorów, 7 – Radzyń Podlaski, 8 – Siedlce, 9 – Warszawa Bemowo, 10 – Warszawa Centrum) water originated from municipal waterworks. In three other sites (11 – Biała Podlaska, 12 – Ruda Wolińska, 13 – Żeliszew Duży) water was sampled from farm wells. Water samples in sites 11 and 13 were taken from dug wells at depths of 15 and 5 m, respectively; in site 12 the sample was taken from a drilled well at a depth of 20 m. In each sampling site, water was collected before and after the instalation of a filter, and at two sites this meant a time gap of ca. 1 month. The analyses were carried out in 2012 and samples from the farm wells were collected in July – August of that year. In total, 26 water samples were collected and each sample was analysed twice. Water samples filtered in a reversed osmosis system and not enriched with additional mineralization were taken for the study. Total hardness, concentrations of calcium and magnesium (titration with sodium versenate) chlorides (argentometric method) nitrates (spectrophotometric method), electrolytic conductivity (with conductivity meter) and pH (potentiometrically) were determined in water samples according to recommendations given in the Regulation of the Minister of Environment (*Regulation* … 2011).

The distribution of the data was tested with the Shapiro-Wilk test. The non-parametric Mann-Whitney U test was used to compare chemical parameters determined before and after the filters. Correlations between the analysed parameters were calculated with the Spearman rank correlation. All calculations were performed with the Statistica 10 software.

RESULTS

The results of determinations of particular components are illustrated in Figures 1 and 2. Table 1 shows values of the analysed parameters and statistical data. The analysed waters were characterised by a great variability of the components. In most samples, water hardness was between 200 and 300 mg $CaCO_3$ dm^{-3}. The water from site 7 was the hardest, while that from site 12 was the least hard. Water hardness was mainly determined by the concentration of calcium ions ($r_s = 0.868$, $p < 0.05$). In most unfiltered water

Table 1

Statistical parameters of analyses of water samples before (BF) and after filter (AF)

Parameter	Before (BF)/ after (AF) filter	Median	Min	Max	*Z*	*p*
$CaCO_3$ (mg dm^{-3})	BF	264.2	146.1	311.3	4.205	<0.0001
	AF	34.00	14.12	198.7		
Mg^{2+} (mg dm^{-3})	BF	9.648	4.538	21.10	4.205	<0.0001
	AF	3.400	1.148	4.860		
Ca^{2+} (mg dm^{-3})	BF	82.24	50.92	113,8	4.103	<0.0001
	AF	9.620	2.510	72,58		
Cl^- (mg dm^{-3})	BF	18.30	3.500	107.0	2.308	0.021
	AF	5.400	1.400	25.50		
NO_3^- (mg dm^{-3})	BF	2.892	0.654	30.55	1.385	0.166
	AF	1.408	0.473	8.414		
Electrolytic conductivity (μS cm^{-1})	BF	555.0	332.0	758.0	4.154	<0.0001
	AF	67.00	17.70	452.0		
pH	BF	7.390	6.810	7.840	4.206	<0.0001
	AF	6.520	4.410	6.930		

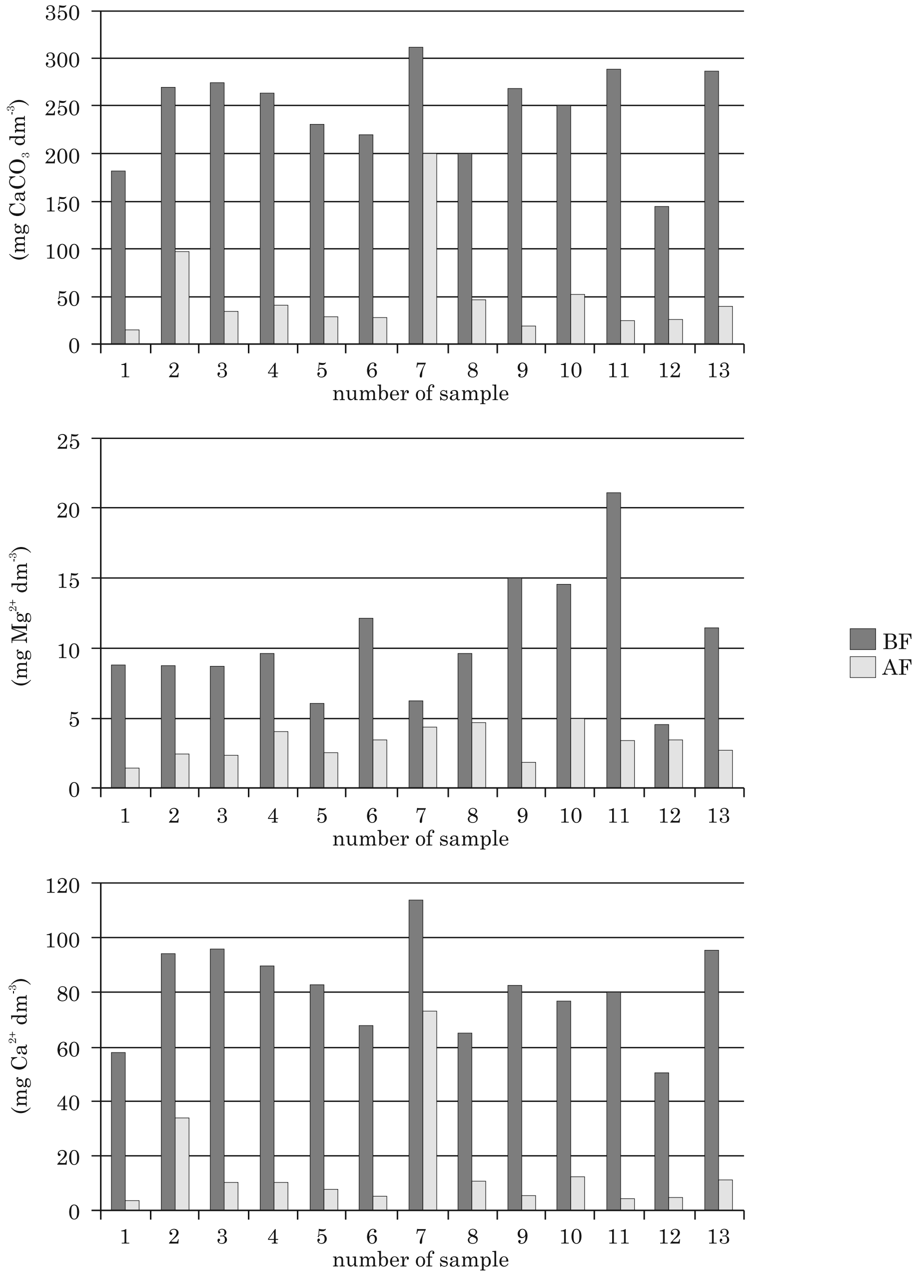

Fig.1.The results of analyses of total hardness and concentrations of magnesium and calcium ions in water before (BF) and after (AF) filter

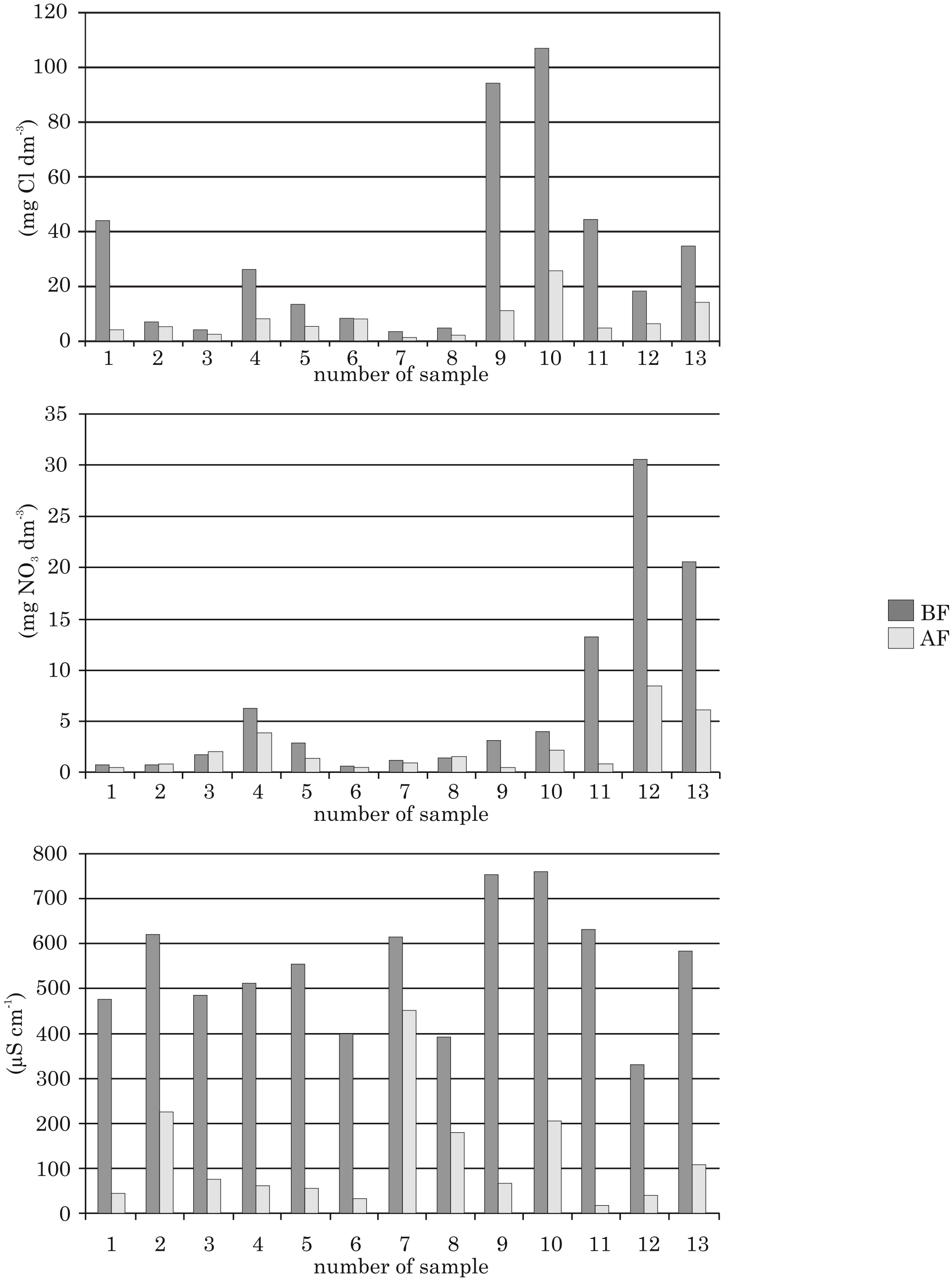

Fig. 2. The results of the analyses concentrations of chloride and nitrate ions and electrolytic conductivity in water before (BF) and after (AF) filter

samples, the calcium concentration exceeded 80 mg dm^{-3}, while in filtered waters this concentration was below 15 mg dm^{-3}. In five samples of unfiltered water, the concentration of magnesium was above 10 mg dm^{-3} and in none of the filtered samples, the magnesium concentration exceeded 5 mg dm^{-3}. The water filters decreased water hardness by 87% on average, including the decrease of Ca ions by 88% and Mg ions by 65% (Figure 1). The Ca : Mg molar ratio was 4.050 and 1.592 in unfiltered and filtered waters, respectively. Using water filters also resulted in the decrease of anion concentrations. This was particularly visible at high concentrations of chlorides and nitrates (Figure 2). The highest concentrations of chlorides (above 90 mg dm^{-3}) were noted in samples from the Warsaw waterworks (sites 9 and 10). Concentrations of nitrates in nine analysed samples of tap water did not exceed 5 mg dm^{-3}. The highest nitrate concentrations (above 10 mg dm^{-3}) were recorded in samples from farm wells (sites 11-13). The process of filtering affected the concentrations of chlorides (mean decrease by 70%) more than nitrates (mean decrease by 50%).

The highest electrolytic conductivity (above 700 μS cm^{-1}) was found in samples from the Warsaw waterworks. In most analysed water samples, the conductivity fell in the range from 400 to 650 μS cm^{-1}. Electrolytic conductivity in filtered waters decreased by *ca* 88% (Figure 2) compared with unfiltered waters. An increase of water acidity was also noted in filtered waters – the mean pH decreased from 7.39 to 6.52. Statistically significant differences of the mean values of water indices between unfiltered and filtered waters were found for all analysed parameters except nitrates (Table 1). Data presented in Figure 2 demonstrate higher concentrations of nitrates in water from farm wells (number of samples 11-13) than in waters from municipal waterworks (number of samples 1-10).

DISCUSSION

The results indicate that water filters installed in household water intakes substantially alter the chemical composition of drinking water. Changes manifest themselves in the decrease of electrolytic conductivity and total hardness due to decreased concentrations of calcium and magnesium. The analyses of total hardness of unfiltered water revealed that the inhabitants of northeast Poland drink water of medium hardness. Filtered water was classified, after Biszof (2010), as very soft ($CaCO_3$ concentration below 100 mg dm^{-3}). Total hardness of unfiltered water in the range from 60 to 500 mg $CaCO_3$ meets the norms set by the Minister of Health (*Regulation* ... 2007). After filtration, however, the concentration of $CaCO_3$ in waters from 11 intakes did not fulfil this requirement. The analytical results indicate that groundwater in the north-east of Poland, irrespective of a sampling site, had very low concentrations of magnesium (no more than 15 mg dm^{-3}).

The magnesium concentration in unfiltered waters was below the obligatory standards – 30-125 mg dm^{-3} (*Regulation* ... 2007). Filtration additionally decreases concentrations of both calcium and magnesium ions.

Long-term consumption of water poor in calcium and magnesium may result in disturbances in the electrolyte equilibrium. Deficit of magnesium may cause diseases of the cardiovascular system, disturbances of the cardiac cycle, weaknesses, vertigos and muscle contraction (Grzebisz 2011, Błaszczyk, Duda-Chodak 2013, Cieślewicz et al. 2013). Pathological conditions associated with systemic magnesium deficiencies may be associated with disturbances of numerous neurophysiological processes, manifesting themselves in migraine (Rybicka et al. 2012). The symptoms of calcium deficiency include excessive neural and muscular excitability (contractions of eyelids, larynx, coronary arteries) and disturbances the cardiovascular system disorders (e.g. ventricular dysrhytmia). Chronic hypocalcemia leads to osteoporosis (Morr et al. 2006), increases the risk of brain stroke and raises blood pressure (Jorde, Bonaa 2000). Supplementing the diet with both elements is very important. As underlined by Knypl (2005), the ions of magnesium, calcium and potassium given simultaneously to geriatric patients interact synergistically and positively affect the functions of the cardiovascular system.

Magnesium and calcium are much better assimilated from water than from food (Januszko et al. 2012), and drinking soft water devoid of these elements may pose a much greater risk than consumption of hard water (Derkowska-Sitarz, Adamczyk-Lorenc 2008). Consumption of highly mineralised waters, as underlined by Salomon and Regulska-Ilow (2013), supplies consumers with appropriate amounts of calcium and magnesium ions and in some cases may even cover the daily demand for these elements.

Research shows that the consumption of 2 litres of unfiltered water covers 10-20% of the daily demand for calcium and 7-14% – for magnesium. Drinking filtered water decreases the contribution of water in RDAs of both elements by several times. Because the magnesium concentrations in unfiltered water were below the level recommended by the Ministry of Health (*Regulation* ... 2007), it is advisable to supplement the diet with magnesium in northeastern Poland. Supplementing the diet with both calcium and magnesium is recommended in the case of drinking filtered water.

Optimum assimilation of calcium and magnesium by the human organism takes place at the 2:1 molar ratio of Ca:Mg in water (Wojtaszek 2006). Water filters favourably alter the Ca:Mg ratio, but this is unimportant when the concentrations of both elements are low (Wojtaszek 2006).

The use of water filters significantly decreased water pH. This effect is directly associated with the concentration of bicarbonate ions co-existing with calcium and magnesium ions in drinking water. Waters rich in bicarbonates alkalise stomach content (exerting positive effect in hyperacidity) and in the initial stages of diabetes they decrease the concentration of glucose in blood and urine (Wojtaszek 2006).

Noteworthy, water components analysed in randomly collected samples of unfiltered water conformed to the requirements for the quality of water intended for human consumption also with respect to chlorides and nitrates (*Regulation* ... 2007).

The concentrations of chlorides in most samples were within the range typical for the hydrogeochemical background, which is 2-60 mg dm^{-3} for Polish groundwaters (*Regulation* ... 2008). Of particular interest was a high (above 90 mg dm^{-3}) concentration of chlorides in samples from the Warsaw waterworks (samples 9 and 10), apparently caused by drinking water chlorination. Samples of water from farm wells showed elevated concentrations of chlorides and nitrates compared with those from most waterworks intakes. Concentrations of nitrates above the groundwater hydrogeochemical background (0-5 mg dm^{-3}) indicate their anthropogenic origin. Due to high concentrations of nitrates, water from farm wells, irrespective of their depth, is of worse quality than water from municipal waterworks intakes.

The results reported here indicate that the installed water filters did not significantly decrease nitrate concentrations in water. In some cases (samples 2, 3 and 8), a slight increase of nitrate concentrations in filtered water was noted. Much attention is paid in the literature to the presence of nitrates in drinking water due to their negative effect on human health (FAO/WHO 2003, Fewtrell 2004, Szczerbiński et al. 2006). Ou results showed that installed water filters did not significantly decrease nitrate concentrations in water samples but favourably decreased the Ca:Mg ratio. However, as pointed out by Wojtaszek (2006), the ratio is of no importance when concentrations of both elements are low.

Noteworthy, water from municipal waterworks is controlled by the State Sanitary Inspectorate and its consumption should not pose a health risk. This was confirmed by results of studies made by Wojtyła-Bucior and Marcinkowski (2010) in Wielkopolska. Water from farm wells is not monitored by sanitary services. In some cases, its regular consumption may pose a health risk to consumers, mainly because of nitrate concentrations exceeding the standards (Raczuk 2010, Raczuk et al. 2013). The claims of manufacturers of water filters that their product may improve water quality mislead consumers. Water filters installed in household water intakes mainly demineralise drinking water (Derkowska-Sitarz, Adamczyk-Lorenc 2008), which was also confirmed in this study. Irrespective of an intake, filtration of water in households without its supplementation with calcium and magnesium markedly decreases the concentration of ions important for proper functioning of the human organism.

CONCLUSIONS

Water filters without additional mineralization installed in households:

- significantly decrease total hardness, concentrations of magnesium, calcium and chloride ions and electrolytic conductivity. They also decrease water pH but do not statistical significantly change nitrate concentrations in drinking water,
- worsen the drinking water quality due to unfavorably decreased concentrations of calcium and magnesium and water pH.

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