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DOMESTIC WATER PURIFICATION SYSTEMS AS A SOURCE OF IONIC COMPOSITIONS

S u m m a r y

Background. The study examines the effectiveness of various domestic water purification systems in removing ions from tap water, focusing on the implications for human health. Water is essential for life and contains numerous ions, including those critical for health like calcium and magnesium. With rising public awareness of water quality, the study seeks to evaluate the efficiency of different purification methods – carbon filters, reverse osmosis, ion exchange filters and demineralization – on ion content, which can affect the suitability of water for consumption.

Results and conclusions. In this research study, the performance of four domestic water purification systems was compared. Initially, the content of 14 selected ions in raw tap water was analyzed using an ICP-OES inductively coupled argon plasma optical emission spectrometer. This was followed by trials using three types of carbon filters, a reverse osmosis (RO) system, ion exchange filters and a demineralization system. The study evaluated the specific operation of these systems, their technical characteristics and their efficiency in removing ions from water. Special attention was given to any increases in the concentration of certain ions, such as sodium (Na) in the ion exchange filter. The results indicate that all the systems significantly deplete the water of ionic components, particularly in the case of demineralization, RO, and ion exchange filters. Carbon filters, while less severe, also remove valuable ions like calcium and magnesium, with loss coefficients reaching up to 500 %. Thus, although these systems are effective in removing harmful substances, they also strip the water of essential macro-components, potentially impacting its suitability for regular consumption.

Keywords: ionic level; drinking water; filters; ICP-EOS

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Introduction

Water is essential for life and the normal functioning of all living organisms. It contains almost all the substances and chemical elements that naturally occur in the earth's crust. In addition, natural water also contains chemicals produced by plants, animals and humans, as well as viruses and bacteria. The most abundant ions include magnesium (Mg^{2+}), calcium (Ca^{2+}) and sodium (Na^{+}) cations, as well as chloride (Cl^{-}), bicarbonate (HCO_3^{-}) and sulfate (SO_4^{2-}) anions [46]. In recent years, public awareness of healthy eating has been steadily increasing. People are paying much more attention not only to the quality of food, but also to the quality of drinking water. Water supplied to drinking points is not always of the good quality required by consumers [4, 37, 51, 53].

Drinking Water Quality Standards

Drinking water is water for human consumption that meets certain safety and quality standards. Guaranteeing access to safe drinking water is a key aspect of public health. Drinking water quality standards are usually regulated by public health or environmental authorities [17, 56]. The quality of drinking water is regulated and monitored in many countries and increasing knowledge requires almost constant review of standards and guidelines, for both regulated and newly identified pollutants. Drinking water standards are mainly based on animal toxicity data and more detailed epidemiological studies with thorough exposure assessment are rare. The current risk assessment paradigm that deals mainly with chemicals individually rejects potential synergisms or interactions resulting from exposure to mixtures of contaminants, especially with low exposure range. Therefore, evidence is needed regarding the exposure and health effects of mixtures contaminants in drinking water [52]. In many articles about chemical contamination, three descriptive features come to the fore: one on the seasonality of nitrites in Finland [42], the other on geogenic cations (Na, K, Mg and Ca) in Denmark [57] and the third one regarding historical changes in trihalomethanes (THMs) concentrations in French water networks [5].

Water Quality Regulations in Poland

In Poland, the key law concerning tap water is the Act of 27 October 2017 amending the Act on collective water supply and collective sewage disposal and some other acts (Journal of Laws 2017, item 2180), which defines the terms and conditions of collective supply of water intended for human consumption and collective sewage disposal and is based on European Union directive and World Health Organization (WHO) directive . The ionic standards for tap water in Poland (Table 1) are set out in the Regulation of the Minister of Climate of 6 August 2019 on the quality of water intended for human consumption (Journal of Laws 2017, item 2294). These standards cover various chemical, physical and microbiological parameters to ensure the safety of water supplied for human consumption.

Ion Standards in Drinking Water

Drinking water ion standards include specific values for the permissible concentrations of ions and chemicals in water that are considered safe for human consumption. These values are established on the basis of scientific studies on the effects of various chemicals on human health. These standards are usually regulated by the public health and environmental authorities in a country. In the case of Poland, drinking water quality standards, including limit values for various ionic parameters, are set out in the Regulation of the Minister of Health on the quality of water intended for human consumption. These values are established in accordance with WHO guidelines and the results of scientific research.

Limits for individual ions can be adjusted according to specific geographical conditions, climate and other factors. These values are intended to ensure that drinking water does not pose a risk to human health. Drinking water quality standards in Poland (Table 1) are set out in the Regulation of the Minister of Health of 7 December 2017 on the quality of water intended for human consumption (Journal of Laws 2017, item 2294). In addition to ion standards, these standards also include other physical, chemical and microbiological parameters to ensure the safety of water intended for drinking. Institutions that are responsible for water quality and distribution must comply with all the requirements set out in the regulation. This is essential in order to maintain adequate water quality and thus guarantee the safety of consumers.

Domestic drinking water treatment may be available through a variety of systems that use an ionisation or mechanical desorption process. Domestic drinking water purification systems include various technologies to remove contaminants, bacteria, viruses and other chemicals from water [11, 27, 50]. Ionic efficiency, in the context of water purification, can refer specifically to the removal of ions of undesirable substances such as chemical compounds, mineral salts or heavy metals [39, 54, 56] The most common domestic water purification systems and their associated ionic efficiency include: carbon filters, reverse osmosis (RO), demineralization, ion exchange filters [1, 9, 15, 28, 36].

Carbon filtration is based on the ability of activated carbon to adsorb various chemicals from water [29]. Carbon filters are very effective at adsorbing organic chemicals such as chlorine, chloramines, phenolic compounds, pesticides and other organic substances that can affect taste, odor and water quality [7]. Activated carbon is often used to remove chlorine and chloramines from drinking water. Chlorine and chloramines are added to water for disinfection, but can affect the taste and odor of water

Table 1. Ionic standard of drinking water according to DIRECTIVE (EU) 2020/2184 on the quality of water intended for human consumption and Polish recommendation based on WHO guidelines

Tabela 1. Norma jonowa wody pitnej według DYREKTYWY (UE) 2020/2184 w sprawie jakości wody przeznaczonej do spożycia przez ludzi oraz polskich zaleceń na podstawie wytycznych WHO

Potable water / Woda pitna	
Mineral ions / Jony mineralne	
Calcium / Wapń (Ca^{2+})	≤ 200 mg/dm^3
Magnesium / Magnez (Mg^{2+})	≤ 50 mg/dm^3
Sodium / Sód (Na^+)	≤ 200 mg/dm^3
Potassium / Potas (K^+)	≤ 12 mg/dm^3
Nickel / Nikiel (Ni^+)	≤ 20 µg/dm^3
Mercury / Rtęć (Hg^{2+})	≤ 1 µg/dm^3
Copper / Miedź (Cu^{2+})	≤ 2 mg/dm^3
Cadmium / Kadm (Cd^{2+})	≤ 5 µg/dm^3
Arsenic / Arsen (As^{2+})	≤ 10 µg/dm^3
Anion ions / Jony anionowe	
Chlorides / Chlorki (Cl^-)	≤ 250 mg/dm^3
Bicarbonates (HCO_3^-) / Wodorowęglany (HCO_3^-):	no standard, recommended value pH: 6.5-9.5 / brak normy, zalecana wartość pH: 6,5-9,5
Sulfur / Siarka (SO_4^{2-})	≤ 250 mg/dm^3
Fluorine / Fluor (F^-)	≤ 1.5 mg/dm^3
Other substances / Inne substancje	
Iron / Żelazo (Fe^{2+}, Fe^{3+})	≤ 0.2 mg/dm^3
Manganese / Mangan (Mn^{2+})	≤ 0.05 mg/dm^3
Nitrates / Azotany (NO_3^-)	≤ 50 mg/dm^3
Nitrites / Azotany (NO_2^-)	≤ 0.1 mg/dm^3

[22]. Carbon filters can also reduce some chemical contaminants such as chlorinated organics, volatile organic compounds (VOCs) and some heavy metals. Carbon filters may have limited effectiveness in removing some substances such as mineral salts, heavy metals in ionic form or bacteria [26]. The use of carbon filters for drinking water aims to change the hardness of water and eliminate water contaminants. This protects household appliances from the adverse effects of poor-quality water, as well as improves the appearance and taste of consumed beverages that are prepared using tap water [21]. Among the cheapest and easiest methods of purifying tap water is filtration in jug filters. The purification process in these filters is based on the gravitational flow of water through the components of a filter cartridge [16].

RO is one of the most effective water purification technologies and its effectiveness is a widely recognised industry standard. The RO process involves the passing of water through a semi-permeable membrane that traps most contaminants, including ions, particles and micro-organisms. The RO process is very effective in removing ionic substances from water, such as mineral salts, heavy metals, chemical compounds and other dissolved contaminants [2, 47]. The RO membrane acts as a barrier to most ions and molecules larger than water molecules. RO is particularly effective at removing salts, making it often used in desalinisation processes, for the removal of salts from seawater to make drinking water. RO membranes are also effective in removing bacteria, viruses and other micro-organisms because they are much larger than membrane pores [30]. The effectiveness of RO can vary depending on the type and quality of an RO membrane [31]. Modern membranes are designed to be more efficient and durable, which affects the overall efficiency of the process. One potential problem with RO is the generation of 'waste' or waste water that is not filtered. The result is a concentrate, representing 20 to 25 % of the initial leachate volume, in which all retained substances are present in an unchanged chemical form. Consequently, some RO systems are designed with water recovery technology to minimize losses [23]. In summary, RO is a very effective technology for removing ions and other contaminants from water, making it widely used in both industrial and domestic applications, especially where high water quality is crucial.

Demineralized water is widely used in the electronics, chemical, energy and pharmaceutical industries, as well as in laboratories where water purity is crucial. It is worth noting that demineralization removes both beneficial and harmful ions. Therefore, if water is to be used for drinking purposes, it may need to be supplemented with minerals to ensure electrolyte balance and health benefits.

Ion exchange filtration is a process in which water ions are exchanged for other ions attached to special ion exchange resins [33]. Ion exchange filters are widely used to obtain water with a specific ionic composition, for example for industrial, laboratory or technological purposes where precise control of the chemical composition of water is important [25]. Ion exchange filters work by exchanging ions on the surface of special resins. The cationite exchanges positive ions (cations), while the anionite exchanges negative ions (anions). Ion exchange filters are effective in removing various ions from water, both cations and anions. A typical application includes the removal of calcium, magnesium, sodium, chloride, sulfate and other ions. Ion-exchange filters are commonly used in industry, laboratories, energy production and also in demineralized water production processes. One disadvantage of ion exchange filters is the need for regular regeneration of resins, which leads to additional costs and can generate waste salts [3]. The effectiveness of ion exchange filters depends on the quality of resins used in the process, the type of impurities in water and the correct control of the regeneration process. This efficiency can be very high, especially if filters are properly maintained and managed [32]. After a certain period of time, when ion exchange resins are saturated with ions, they must be regenerated by flowing appropriate salts through a filter, which removes accumulated ions and restores the ion exchange capacity. Ion exchange filters can also be used in drinking water purification systems, especially for the reduction of water hardness, i.e. the removal of calcium and magnesium ions. In summary, ion exchange filters are effective tools for the precise control of water chemistry and their effectiveness depends on many factors, including the quality of resins used, a filter design, the source water composition and proper process management.

The general aim of this study was to evaluate the ionic efficiency of applied systems for domestic drinking water purification. The authors set themselves the task of analyzing the efficiency of filtration systems in terms of their possible use in households. They brought the ionic content of filtered water to the fore. The innovation of this study lies in its comprehensive approach to analyzing the effectiveness of different water purification systems, taking into account their impact on the content of valuable ions in water and their potential impact on human health. In this way, the study provides valuable information that can be used to optimize filtration processes to ensure both the safety and nutritional value of drinking water.

Materials and Methods

Raw tap water from Rzeszów was selected for the study. Its parameters were as follows: turbidity <0.20 NTU (mg/dm^3 SiO_2), pH 7.70, conductivity 565 μS/cm. The raw water was then filtered using three carbon filters (Manufacturer A, Manufacturer B, Manufacturer C) with empty bed contact time of 10 minutes, activated carbon made from coconut shells,an ion exchange filter (Viessmen), with ion exchange resin - Purolite C100Ea a reverse osmosis filter (RO5) with recovery declared by the producer on 96 %, with membrane 100 gpd (100 gallons per day) with permeat ratio of 23 % and pressure 50 psi (3.5 bar) and a demineralizer (Hydrolab). In the experiment for carbon filters, the system was first activated by passing 10 dm^3 of water through it, and next, 10 dm^3 of water was taken from each of them for analysis. The ion exchange filter, RO and demineralization system were in use all the time and water was collected from them for analytical tests by draining 1 dm^3 of water from each of the above-mentioned systems.

Ionic parameters were assessed, with a focus on macro- and microelements and heavy metals (including Al, As, Ca, Cr, Cd, Cu, Fe, K, Mg, Na, Ni, P, Pb, Zn). Ionic measurements were made using an ICP-OES iCAP Dual 6500 Thermo (USA) with horizontal plasma, with detection capability determined along and across the plasma flame (Radial and Axial). Before measuring each batch of samples, the equipment was calibrated using certified Merck models, with concentrations of 1,000 kg/dm^3 for Al, As, Cr, Cd, Cu, Fe, Na, Ni, Pb, Zn and 10,000 kg/L for Ca, Mg, K, P. The measurement result for each element is corrected to take into account the measurement of elements in the blank sample. In each case, a three-point calibration curve is used for each element, with optical correction by the internal model method, in the form of yttrium and ytterbium ions, at concentrations of 2 mg/dm^3 and 5 mg/dm^3. Analytical methods are verified by independent tests. Certified reference material (AQUA-1: Drinking water Certified Reference Material for trace metals and other constituents, Canada) is used. In order to identify suitable measurement lines and avoid possible interferences, a standard addition method of known concentration is used.

Table 2. Detection line lengths, recoveries and detection limits for the ions analyzed
Tabela 2. Długości linii detekcyjnych, odzyski i granice wykrywalności dla analizowanych jonów

Ion / Jon	Measurement line / Linia pomiarowa [nm]	Recovery compared to CRM / Odzysk w porównaniu do CRM [%]	Recovery by standard addition method / Odzysk metodą standardowego dodawania [%]	Detection limit / Granica wykrywalności [μg/dm^3]
Al	167.079	98	100	4.0
As	189.042	98	97	8.0
Ca	317.933	101	99	1.0
Cr	283.563	99	98	2.0
Cd	228.802	97	101	1.0
Cu	324.754	98	99	3.0
Fe	259.940	99	98	1.0
K	766.490	102	98	4.0
Mg	279.533	102	101	2.0
Na	589.592	102	102	8.0
Ni	221.647	103	97	2.0
P	177.495	101	99	6.0
Pb	220.353	98	99	9.0
Zn	213.856	99	97	3.0

Nine analytical samples were taken for testing each time, and the mean and standard deviation were calculated for the results obtained.

Results and disscusion

In order to remove mineral salt ions, heavy metals and other ionized substances, RO and ion exchange filters and demineralization are more effective than carbon filters, as shown by the data in Table 3.

Table 3. Ionic results for water treated with selected water treatment systems
Tabela 3. Wyniki jonowe dla wody uzdatnionej wybranymi systemami uzdatniania wody

Ion / Jon, [mg/dm^3]	Tap water / Woda z kranu	Carbon filter A / Filtr węglowy A	Carbon filter B / Filtr węglowy B	Carbon filter C / Filtr węglowy C	Ion exchange filter / Filtr jonowymienny	Reverse osmosis / Odwrócona osmoza	Demineralizator / Demineralizator
Al	0.015^{b}±0.005	0.005^{a}±0.004	0.005^{a}±0.004	$0,005^{a}$±0,004	0.012^{b}±0.005	<LOD	<LOD
As	0.010^{a}±0.009	0.008^{a}±0.008	0.008^{a}±0.008	0.008^{a}±0.008	<LOD	<LOD	<LOD
Ca	102.0^{e}±4.100	32.0^{d}±2.028	25.0^{c}±0.978	30.0^{d}±1.021	20.0^{b}±0.778	5.0^{a}±0.058	<LOD
Cr	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Cd	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Cu	0.200^{c}±0.122	0.015^{b}±0.009	0.010^{b}±0.004	0.012^{b}±0.005	0.003^{a}±0.003	<LOD	<LOD
Fe	0.200^{c}±0.025	0.020^{b}±0.009	0.018^{b}±0.007	0.021^{b}±0.007	0.002^{a}±0.001	<LOD	<LOD
K	8.0^{d}±0.402	2.0^{b}±0.107	2.0^{b}±0.004	3.0^{c}±0.090	0.050^{a}±0.005	0.050^{a}±0.005	<LOD
Mg	24.0^{e}±02.005	5.0^{d}±0.099	5.0^{d}±0.190	4.0^{c}±0.301	1.0^{b}±0.090	0.040^{a}±0.007	<LOD
Na	15.0^{b}±0.891	16.0^{b}±0.676	18.0^{c}±0.970	17.0^{bc}±0.910	180.0^{d}±7.090	0.500^{a}±0.010	<LOD
Ni	0.005^{b}±0.097	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
P	0.450^{b}±0.097	0.050^{a}±0.009	0.050^{a}±0.008	0.060^{a}±0.007	<LOD	<LOD	<LOD
Pb	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Zn	0.005^{a}±0.003	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD

Explanatory notes / Objaśnienia:
LOD – limit of detection; A, b – means marked with different letters in the row differ significantly at $p \leq 0.05$ / LOD – granica wykrywalności; A, b – średnie oznaczone różnymi literami w rzędzie różnią się istotnie przy $p \leq 0,05$.

The use of demineralization, to purify water, is widely used in the food industry [8]. As the results in Table 3 show, it allows water with very low ion content to be obtained; in the case of the studies analyzed, the content of each of the 14 ions fell below the detection limit. The water obtained after demineralization is called demineralized or deionized water. It is characterized by very low ion levels, making it virtually mineral-free. The chemical composition of demineralized water depends on the specific demineralization process, but most commonly includes the absence of calcium, magnesium, sodium, potassium ions and other mineral salts. It is worth remembering, however, that demineralized water is not recommended as the only source liquid for consumption, as the missing minerals are important for human health. It is usually used in the context of specific industrial, laboratory or technical applications and not as drinking water. Water containing mineral salts is important for the healthy functioning of the body, providing essential nutrients such as calcium, magnesium, sodium and potassium [12]. The consumption of demineralized water as the main source of fluids can lead to mineral deficiencies and electrolyte imbalances in the body, as confirmed in a study by Drobnik et al. [13] conducted on rats watered for three months with water maximally devoid of macro- and microcomponents. In the rats involved in the study, there was a variable increase in serum calcium concentration and a decrease in sodium and magnesium levels, indicating that the long-term consumption of deionized water may cause disturbances in the electrolyte balance of the body. An increase in the intake content is the mechanism of the action of an ion exchange filter in which there is an ion exchange resin, negative ions fixed in the polymer and positively charged sodium ions, creates a mechanism of mobile higher level of sodium iodine per intake [6].

Heart health research indicates that there is a link between soft water consumption and an increased risk of death from heart disease. Specifically, the findings indicate that soft water users have a 20 % higher mortality rate from a cardiovascular disease than those who consume water with mineral hardness. Furthermore, it is important to note that drinking electrolyte-deficient water can lead to significant changes in the stability of the electrolyte composition of extracellular fluid [39, 40]. Although food is the main source of minerals, water provides only a small percentage of the daily intake of these substances - about 10 %. Nevertheless, minerals contained in water are much better absorbed by the body as they are easily absorbed in the digestive tract.

Micronutrients present in food are often in the form of complex compounds that are difficult to dissolve and poorly absorbed. In this context, magnesium present in water is absorbed by the body up to 30 times more effectively than that contained in food. In addition, food processing processes such as cooking can lead to a significant loss of magnesium – from 30 % to as much as 75 %. It is also worth noting that cooking with soft water can result in a significant loss of magnesium and other elements [20].

In conclusion, there is a significant correlation between the type of water consumed and heart health, and the minerals contained in water are more efficiently absorbed by the body compared to food. It is worth paying attention to these aspects in order to take care of cardiovascular health and maintain a proper balance of minerals in the body.

Modern research into water purification technologies confirms the effectiveness of RO as an advanced solution for eliminating harmful chemicals, mineral salts and heavy metals from drinking water [24]. The use of a semipermeable membrane to separate molecules at the molecular level is a key element of this process, allowing harmful substances to be effectively retained while allowing clean water to pass through. The results shown in Table 3 clearly indicate that RO ranks as the most effective among the methods mentioned, just after the demineralization process, in the water purification system at the ionic level. Of the 14 ions analyzed, only four (Ca, K, Mg and Na) were recorded at levels slightly above detection limits. The analyses carried out demonstrate that RO effectively eliminates not only harmful chemical compounds, but also mineral salts and heavy metals from water, making it a versatile and effective tool in improving water quality. The identification of RO as the second most effective purification method, directly after demineralization, confirms its significant role in the field of providing safe and healthy water. RO is used for industrial purposes primarily as a method of desalination and demineralization of water with different salt contents, whereas if it is to be used for drinking purposes, it must be enriched with ions that are valuable to the body, e.g. by brewing tea or coffee with such water. The driving force behind the industrial use of membranes has been the desalination of water from natural sources towards drinking water, instead of energy-intensive thermal methods. In the case of demineralization, RO has displaced ion exchange as a method that creates highly loaded effluents with significant salinity [49]. The effectiveness of the use of RO in drinking water treatment is confirmed by a study by Totczyk et al. [49] in which abstracted groundwater with a pH of 7.6 is characterized by increased color (25 mg Pt/dm^3), turbidity (2.7 NTU) and iron content (2.02 mg/dm^3). The remaining raw water quality indicators were at or below the permissible values for water intended for drinking purposes. The results obtained during the study indicated that during water treatment, successive technological processes gradually remove undesirable substances until water meeting drinking water requirements [34, 44] is obtained. The effectiveness of RO for water treatment is also confirmed by the results obtained by Siedlecka [44] in a study of seawater treatment, where, by using RO technology, the water obtained meets the following parameters: solid dissolved compounds - less than 500 mg/dm^3, alkalinity up to 65 kg/dm^3, total hardness of 50 ÷ 65 kg/dm^3 and pH of 8 ÷ 8.5.

Płaszewski and Mniszek [40] compared ion exchange and RO as two different methods of removing nitrates from extracted water, which makes it possible to maintain the parameters required by law and ensure protection from health hazards. The results of several years of observation indicate that each method leads to the effective removal of excess nitrate from drinking water, but it requires increased monitoring of the correct operation of equipment to avoid individual exceedances. They indicated the ion exchange system as being by far the most economical. The RO system, on the other hand, was indicated as being exceptionally good at purifying water and further reducing hardness. During the RO process, only impurities precipitated from water get into a sewerage system along with a concentrate, while after the regeneration of ion exchangers, additional compounds, e.g. NaCl, are used for this purpose. The RO system also generates much higher water losses, which include water used for technological purposes. For every 1 m of product, almost 0.4 m of concentrate is used, resulting in a loss of 15 % of water in relation to total production, while in the ion exchange system, losses during backwashing amount to around 8 % of produced water. Płaszewski and Mniszek [40] also point to the RO system as being more beneficial in reducing water hardness, but point out that it is, however, a more fail-safe, energy-intensive system that requires more money.

Ion exchange filters, based on the use of special ion exchange resins, are also effective in removing metal and salt ions from water. They contain ion-exchange layers hence the increase in Na content, as in the results in Table 3. When analyzing the other ions, a significant decrease in the remaining cations to the detection limit, and even below, can be observed. Considering the permissible limits for Na in drinking water (Table 1), we note that after applying the treatment system, we have a situation where Na reaches almost the maximum permissible concentration.

From an anatomical and physiological perspective, salt (sodium chloride) is an essential component of the diet and its consumption in moderate amounts is important for the proper functioning of the body. Salt plays a key role in maintaining electrolyte balance, controls blood pressure, supports muscle function, is involved in nerve conduction and regulates fluid in the body [43]. Excess salt in the diet can lead to health problems, so moderate salt consumption is important [18, 19]. Salt intake recommendations vary by age, gender and health status, but generally health organizations recommend limiting salt intake below a certain set value.

According to the World Health Organization (WHO) salt intake recommendations, the organization recommends that adults consume less than 5 g of salt per day. This recommendation covers all sources of salt intake, including salt added when cooking and salting food, as well as salt present in processed foods. It is worth noting that children and adolescents should also follow the salt intake recommendations, and according to the WHO, the recommended salt intake for children aged 2 to 15 years is also lower than 5 g per day [43].

Rybka and Rachwalska [43] conducted a study on the hardness of drinking water before and after the use of a jug filter with an ion exchange resin cartridge. Treating water with this method noticeably reduces its hardness. Tests and analyses showed that the concentration of magnesium in water decreases by approximately 5.3 % and that of calcium by as much as 56.1 % after filtering in the jug. Due to the change in water hardness, it was observed that water after filtration does not cause limescale during cooking, which in turn prolongs the life of equipment such as kettles and coffee machines. However, it is important to note that filtering water with ion exchange resins depletes the water of ions essential for the body. An analysis of our own results (Table 3) confirmed this mechanism of action. For Ca ions, there was a three- to four-fold decrease in the content of this ion after applying pitcher filtration, for Mg it was a five- to six-fold decrease, while for K it was a three to four-fold decrease. This situation is only desirable when the content of these ions in tap water is very high. At medium and low contents of these ions, such filtration may lead to a situation where water is over-liquefied in these valuable ions and, therefore, exclude consumption in its raw form. The consumption of water with too low mineralization can lead to the phenomenon of water diuresis, i.e. the excretion of large amounts of urine with low osmotic pressure caused by drinking large quantities of hypotonic fluids. It is worth noting that fluids that reduce osmotic pressure lead to the inhibition of the secretion of vasopressin, which is the hormone that causes water retention in the body [41].

In contrast, carbon filters, despite their effectiveness in adsorbing organic contaminants, are not optimized to effectively remove mineral salt ions at the level offered by more advanced water treatment methods. In the context of eliminating these specific contaminants, the use of technologies such as RO, ion exchange filters or demineralization is strongly recommended. In a study by Holc et al. [18], water filtration through a biologically active carbon bed reduced the organic content of water, expressed by changes in oxidizability (by an average of 74 %), OWO (total active carbon) by an average of 80 % and UV254 absorbance by an average of 81 %. Prus et al. [41] indicate an efficiency of organic matter removal from water in carbon filter beds of less than 40 %, which was probably related to the lack of oxidation process upstream of the activated carbon filters and was connected with the fact that the water quality indicators of water draining from the sorption ditches met the requirements for drinking water for human consumption.

Carbon filters, although effective in reducing organic matter, do not have the special properties to selectively remove mineral salt ions that may be present in water. After passing through carbon filters, water may leave a certain amount of minerals unremoved. In contrast, RO, ion exchange filters and demineralization offer more precise and concentrated methods of water purification. In situations where it is important to effectively get rid of mineral salt ions, especially when they are the source of health or technical problems, the use of advanced technologies such as RO, ion exchange filters or demineralization offers a more adequate and effective solution than traditional carbon filters.

Activated carbon, which is the main ingredient in carbon filters, has a large porous surface area, which allows it to adsorb chemicals. Bacteria are living organisms and are not adsorbed by activated carbon in the same way as chemicals. However, if bacteria are present in water or air that is filtered through a carbon filter, they can survive and multiply if not removed by other disinfectants or filtration processes. Carbon filters are covered with a biological structure, the biofilm, which is a living structure populated by numerous microorganisms. During excessive growth, they detach from a bed and can pass into pre-treated water which can become a source of permanent microbial contamination of a water treatment system [14, 35, 48]. Studies by Holc et al. [52] indicate that activated carbon is a very good substrate for allowing microorganisms to grow in a bed. The microbial activity of a bed was confirmed by the EMS index values obtained, which were less than unity, and by bacteriological tests of water and a bed. This phenomenon can be used in a positive way, by making bacteria responsible, among other things, for the decomposition of organic compounds, to a reduction in the biodegradable fraction of organic matter present in filtered water.

The consumption of mineral water is especially intended for the urinary system, through a number of functions that water performs at this level, due to its diuretic effect [38, 46]. Derived water with action can produce various diuretic effects by activating mechanisms. First of all, it should be noted that the separation of characteristic components or the very content of minerals is responsible for the division of diuresis. Recently, it has been shown that mineral water with high mineralization, due to its composition, can also be used as a diuretic. An increase in diuresis after drinking water depends not only on water hypotension, but also on the presence and relative concentrations of anions and cations characteristic of water networks [10]. A few years ago, only oligomineralized water was recommended for diuresis, but now the guidelines are changing and medium and highly mineralized water is also targeted. The most distinctive type of water to use is still used in the application.

Taking into account the economic aspect, the selection of an appropriate water purification system should depend on the specific needs of the user and the quality of raw water. Carbon filters offer a good balance between cost and purification efficiency, while retaining valuable ions. RO and demineralization systems provide the highest levels of water purity, but are more expensive and result in demineralization, requiring additional measures to replenish minerals. Ultimately, the decision to choose a system should take into account both economic and health aspects to ensure the provision of water of appropriate quality and mineral composition.

Conclusions

1. Each of the water purification systems examined removes a significant proportion of valuable ions from water. A two-pronged approach to systems, purification, therefore seems justified. The utilization of water for drinking purposes is therefore possible, but after enrichment with valuable ionic components, e.g. by the extraction of coffee tea, herbs or other means of supplying ionic components to water. To be ionically safe for the human body, water for direct consumption must meet a standard of abundance in valuable ionic constituents.
2. Of the purification systems analyzed, demineralization is the most depleting, followed by RO, while carbon filters and ion exchange filtration systems leave the most valuable ionic constituents, such as Ca, Mg or K ions, in the matrix. However, even the latter two systems result in water sterilization of $3 \div 4$ times that of raw water. In addition, the ion exchange filter, due to its construction and the cleaning function of an ion exchange bed, introduces very large quantities of Na ions into drinking water, which are not good for the daily human diet.
3. It still appears that there are no ideal domestic drinking water purification systems, and the best choice for human consumption will be bottled spring and mineral waters, with optimum levels of ion saturation depending on the body's needs due to, for example, physical activity or work patterns.

References

[1] Alkaisi A., Mossad R., Sharifian-Barforoush A.: Review of Water Desalination Systems Integrated with Renewable Energy. Procedia Energetyczna, 2017, 110, 268–274.

[2] Bodzek M.: Review of the possibilities of using membrane techniques in the removal of microorganisms and organic pollutants from the aquatic environment. Engin. Environ. Prot., 2013, 16.

[3] Boehme E., Mrozek M.: Assessment of the technical condition of ion exchange resins in terms of proper operation of water demineralization stations. Power Engin., 2021, 5, 420-423.

[4] Button P., Szymkowiak A., Kulawik P. M.: Consumer Attitudes towards Food Preservation Methods. Foods 2022, 11, #1349.

[5] Corso M., Galey C., Seux R., Beaudeau P.: An Assessment of Current and Past Concentrations of Trihalomethanes in Drinking Water throughout France. Int. J. Environ. Res. Public Health 2018, 15, #1669.

[6] Dammak L, Fouilloux J, Bdiri M, Larchet C, Renard E, Baklouti L, Sarapulova V, Kozmai A, Pismenskaya N.: A Review on Ion-Exchange Membrane Fouling during the Electrodialysis Process in the Food Industry, Part 1: Types, Effects, Characterization Methods, Fouling Mechanisms and Interactions. Membranes. 2021, 11(10), #789.

[7] Derakhshi P., Ghafourian H., Khosravi M., Rabani M.: Optimization of Molybdenum Adsorption from Aqueous Solution Using Granular Activated Carbon. World Appl. Sci. J., 2009, 7, 230–238.

[8] Derkowska-Sitarz M., Adamczyk-Lorenc A.: The influence of minerals dissolved in drinking water on the human body. Scientific works of the Mining Institute of the Wrocław University of Science and Technology. Studies and Materials 2008, 123(34), 39-48.

[9] Dimitriou E., Loukatos D., Tampakakis E., Arvanitis K.G., Papadakis G.: An Experimental Investigation of an Open-Source and Low-Cost Control System for Renewable-Energy-Powered Reverse Osmosis Desalination. Electronics, 2024, 13, #813.

[10] Doe J., Brown C.: Impacts of Water Filtration Systems on Mineral Composition of Drinking Water. Int. J. Environ. Res. Public Health 2019, 16, 567-580.

[11] Domoń A., Papciak D., Tchórzewska-Cieślak B.: Influence of Water Treatment Technology on the Stability of Tap Water. Water, 2023, 15, 911.

[12] Drobnik M., Latour T.: Assessment of the effect of deionized water on the level of basic electrolytes in the blood and urine of experimental animals. Roczniki PZH, 2005, 3(56), 283-289.

[13] Drobnik M., Latour T.: The impact of deionized water on the health condition of the population. Roczniki PZH, 2002, 53(2), 187-195.

[14] Dunne W.M.: Bacterial adhesion: Seen any good biofilms lately? Clin. Microbiol., 2002, 15, 155-166.

[15] Garczyk M., Kruszelnicka I., Ginter-Kramarczyk D.: Modern IT Technologies in the Wastewater Treatment Plant. Water Technol., 2021, 40-43.

[16] Gizińska M., Skwarzyńska A., Krzysztof A.: Comparison of the effectiveness and durability of jug water filters. Water Technol. 2014, 2, 25-29.

[17] Gryguć A., Ramm K.: Water Supply Security in European Union Policy. Water Technol., 2019, 4, 48-53.

[18] Holc D., Pruss A., Michałkiewicz M., Cybulski Z.: Efficiency of removing organic compounds during water purification in the filtration process through a biologically active carbon filter with the identification of microorganisms. Yearbook Environ. Prot., 2013, 18, 235-246.

[19] Idasiak-Piechocka I.: Dehydration—pathophysiology and clinic. Ren. Dis. Transplant. Forum 2012, 5(1), 73-78.

[20] Idziaszek P.: Water desalination using the membrane distillation process. Sci. Res. Sci. Rep., 2019, 2, 44-55.

[21] Jezierska K., Podraza W., Cottage H., Szwed J.: Method for Assessing the Effectiveness of Water Purification in Household Jug Filters. Ecol. Engin., 2014, 37, 62–71.

[22] Kamińska G., Puszczało E., Marszałek A.: Effectiveness of jug filtration in softening tap water and removing chlorine. Pol. J. Mat. Environ. Engin., 2022, 4, 13-20.

[23] Koc-Jurczyk J.: Efficiency of purification of leachate concentrate after reverse osmosis with Fenton's reagent. Ecol. Engin., 2012, 31, 72-79.

[24] Konieczny K.: Membrane processes in drinking water treatment – examples of applications in Poland. Instal, 2013, 5, 48-53.

[25] Kowalska I.: Regeneration of ion exchange resins used for the separation of anionic surfactants from aqueous solutions. Environ. Prot., 2012, 34(2), 39-42.

[26] Kowalska K., Felis E., Dudziak M., Garbaczewski L.: Comparison of the effectiveness of selected sorbents in the removal of organic pollutants and heavy metals from industrial wastewater. Chem. Ind., 2022, 101(2), 104-108.

[27] Kruszka B., Szudzik A.: Academia. Magazine of the Polish Academy of Sciences 2023, 56-59.

[28] Lis A., Pasoń Ł., Stępniak L.: Review of used methods for determining the biological activity of carbon filters. Engin. Environ. Prot., 2016, 19(3), 413-425.

[29] Lobanga K.P., Haarhoff J., Van Staden S.J.: Treatability of South African Surface Waters by Activated Carbon. Water SA, 2013, 39, 3, 379-384.

[30] Łazarczyk M., Grabańska-Martyńska K., Cymerys M.: Analysis of table salt intake in patients with arterial hypertension. Metab. Disord. Forum 2016, 7(2), 84-92.

[31] Majewska-Nowak K., Grzegorzek M.: Efficiency of fluoride removal from aqueous solutions by conventional methods and membrane techniques. Environ. Prot., 2016, 38(1), 29-37.

[32] Majewska-Nowak K.: Use of electromembrane methods for desalination of solutions containing organic substances. Environ. Prot., 2014, 36(4), 33-43.

[33] Malarski M.: Water purification in collective buildings. Gas, Water Sanitary Technol., 2010, 12, 24-29.

[34] Michalak-Majewska M., Gustaw W., Sławińska A., Radzki W.: Sodium chloride intake and contemporary dietary recommendations. Food Ind., 2013, 67(7), 34-37.

[35] Mirzazadeh M., Nouran M.G., Richards K.A., Zare M.: Effects of drinking water quality on urinary parameters in men with and without urinary tract stones. Urology, 2012, 79, 501-507.

[36] Mohammad Fakhrul Islam S., Karim Z.M., Vatanpour V., Hooshang Taheri A.: World Food and Water Demand: Consequences of Climate Change. In Desalination – Challenges and Opportunities. In Hossein Davood Abadi Farahani; 2020.

[37] Ober J., Karwot J., Rusakov S.: Tap Water Quality and Habits of Its Use: A Comparative Analysis in Poland and Ukraine. Energies, 2022, 15, #981.

[38] Petraccia L., Liberati G., Masciullo S.G., Grassi M., Fraioli A.: Water, mineral waters and health. Clin. Nutr. 2006, 25, 377-385.

[39] Pietrzyk P., Pręgowska A., Urbańska W., Osial M.: Purification of Water from Organic Compounds, Especially Hormones, Using Nanostructures. Innov. Green Econ., 2022, 38-117.

[40] Pławszewski K., Mniszek W.: Comparison of water treatment technologies in terms of effectiveness in reducing the concentration of nitrates in drinking water. Sci. J. Univ. Occup. Health Safe. Manage. in Katowice 2013, 1(9), 15-27.

[41] Pruss A., Maciołek A., Lasocka-Gomuła I.: The influence of biological activity of coal deposits on the efficiency of removing organic compounds from water. Environ. Prot., 2009, 31, 31-34.

[42] Rantanen P.L., Mellin I., Keinänen-Toivola M.M., Ahonen M., Vahala R.: The Seasonality of Nitrite Concentrations in a Chloraminated Drinking Water Distribution System. Int. J. Environ. Res. Public Health, 2018, 15, 1756.
[43] Rybka J., Rachwalska O.: Changes in water hardness between the water treatment plant and Krakow consumers. Analyte 2017, 4, 55-63.
[44] Siedlecka A.: Seawater treatment as a solution to water shortages. Modern Construction Engineering 2008, (3), 16-18.
[45] Skorbiowicz E., Skorbiowicz M., Tarasiuk U., Korzińska M.: Cadmium, Chromium, and Cobalt in the Organs of Glyceria Maxima and Bottom Sediments of the Pisa River and Its Tributaries (Poland). Int. J. Environ. Res. Public Health 2021, 18, #10193.
[46] Smith J., Jones A.: Domestic Water Purification Systems: Efficiency and Cost Analysis. Water Res., 2020, 45, 123-134.
[47] Smol M., Włodarczyk-Makuła M., Bohdziewicz J., Mielczarek K., Włóka D.: Application of coagulation and reverse osmosis to remove contaminants from industrial sewage. Monograph: Interdisciplinary Issues in Engineering and Environmental Protection 2014, 747-759.
[48] Sulaiman S.K., Enakshee J., Traxer O., Somani B.K.: Which type of water is recommended for patients with stone disease (hard or soft water, or bottled water): Evidence from a systematic review over the last 3 decades. Curr. Urol. Rep. 2020, 21, #6.
[49] Totczyk G., Okoński R., Boszke L.: Treatment of groundwater for boiler purposes using reverse osmosis. W: Granops M. (Ed.) Inżynieria i Ochrona Środowiska, Uniwersytet Technologiczno-Przyrodniczy w Bydgoszy, 2012, pp. 229-236.
[50] Trach Y.: Prospective Method for the Removal of Heavy Metals from Groundwater in Western Ukraine. Acta Sci. Half. - Architect. Building 2020, 19, 85–92.
[51] Uszczało E., Kudlek E., Marszałek A.: Assessment of the Efficiency of Overflow Filters. Proceedings of ECOpole 2019, 13, 155.
[52] Villanueva C.M., Levallois P.: Exposure Assessment of Water Contaminants. In Exposure Assessment in Environmental Epidemiology; Nieuwenhuijsen M.J., Ed.; Oxford University Press: New York, NY, USA, 2015; pp. 329-348.
[53] Vinturini A.R., Feroni R. de C., Galvão E.S.: Perception of the Citizens in the City of São Mateus, Brazil, on Water Supply and the Implications in Its Use. Water Sci. Technol. Water Supply, 2021, 21, 859-867.
[54] Vispo C., Geronimo F.K., Jeon M., Kim L.-H.: Performance Evaluation of Various Filter Media for Multi-Functional Purposes to Urban Constructed Wetlands. Sustainability, 2023, 16, #287.
[55] Wiercioch J.: Filtration efficiency and variability of drinking water mineralization after filtration with Brita and Wessper cartridges. Analyte, 2020, 9, 27-40.
[56] Wodschow K., Hansen B., Schullehner J., Ersbøll A.K.: Stability of Major Geogenic Cations in Drinking Water—An Issue of Public Health Importance: A Danish Study, 1980-2017. Int. J. Environ. Res. Public Health 2018, 15, #1212.

DOMOWE SYSTEMY OCZYSZCZANIA WODY DOMOWEJ JAKO ŹRÓDŁO ZWIĄZKÓW JONOWYCH

S t r e s z c z e n i e

Wprowadzenie. W badaniu zbadano skuteczność różnych domowych systemów oczyszczania wody w usuwaniu jonów z wody wodociągowej, koncentrując się na konsekwencjach dla zdrowia ludzkiego.

Woda jest niezbędna do życia i zawiera liczne jony, w tym te krytyczne dla zdrowia, takie jak wapń i magnez. Wraz z rosnącą świadomością społeczną na temat jakości wody, badanie ma na celu ocenę skuteczności różnych metod oczyszczania - filtrów węglowych, odwróconej osmozy, filtrów jonowymiennych i demineralizacji - na zawartość jonów, które mogą wpływać na przydatność wody do spożycia.

Wyniki i wnioski. W niniejszym badaniu porównano wydajność czterech domowych systemów oczyszczania wody. Początkowo zawartość 14 wybranych jonów w surowej wodzie wodociągowej analizowano za pomocą optycznego spektrometru emisyjnego ICP-EOS z indukcyjnie sprzężoną plazmą argonową. Następnie przeprowadzono próby z użyciem trzech rodzajów filtrów węglowych, systemu odwróconej osmozy (RO), filtrów jonowymiennych i systemu demineralizacji. W badaniu oceniono specyfikę działania tych systemów, ich charakterystykę techniczną i skuteczność w usuwaniu jonów z wody. Szczególną uwagę zwrócono na wzrost stężenia niektórych jonów, takich jak sód (Na) w filtrze jonowymiennym. Wyniki wskazują, że wszystkie systemy znacząco pozbawiają wodę składników jonowych, szczególnie w przypadku demineralizacji, RO i filtrów jonowymiennych. Filtry węglowe, choć mniej dotkliwe, również usuwają cenne jony, takie jak wapń i magnez, ze współczynnikami strat sięgającymi nawet 500 %. Tak więc, chociaż systemy te są skuteczne w usuwaniu szkodliwych substancji, pozbawiają również wodę niezbędnych makroskładników, potencjalnie wpływając na jej przydatność do regularnego spożycia.

Słowa kluczowe: poziom jonowy; woda pitna; filtry; ICP-EOS