

The effect of water filter cartridges on the hardness and the mineral concentration of tap water

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ABSTRACT

This study compared the effectiveness of six different filter cartridges as regards removing water hardness, pH changes, conductivity, and calcium and magnesium ion concentrations. Two of these cartridges are standard, two are designed for very hard water due to their enhanced hardness-removal properties, one filter is designed to increase water pH, and one is designed to enrich water with magnesium ions. The test was performed on tap water with a total hardness of 394 mgCaCO₃/dm³, pH 7.05, conductivity 731 μS/cm, Mg concentration 16.99 mg/dm³, and Ca concentration 106.24 mg/dm³. A total of 150 dm³ of water was filtered throughout each cartridge, with changes in its physicochemical parameters being analyzed at successive stages of cartridge exploitation. The results showed that the filters were most effective during the initial stage of filtration, and their efficiency gradually decreased as the volume of filtered water increased. Research confirmed that jug filters can effectively reduce water hardness; however, their efficiency is largely dependent on the cartridge's wear rate.

Keywords: jug filtration, water quality, tap water, water hardness.

INTRODUCTION

In recent years, as a result of social campaigns encouraging tap water consumption, consumer interest in its quality has increased. The water supplied to consumers should meet the requirements imposed by the Regulation of the Minister of Health of May 22nd, 2026 on the quality of water intended for human consumption (Regulation 2026). Unfortunately, the composition of water injected into the network often differs from that of the water supplied to consumers. Despite taking a number of measures to ensure the highest possible level of water quality throughout the distribution system, the possibility of secondary water contamination cannot be completely eliminated. Oversizing networks and reduced water consumption result in a decrease in water flow rate in networks. Such network working conditions cause stagnation and increase the risk of

secondary water contamination (Jachimowski 2017, Wang 2025). Water contamination can result not only in changes in color, turbidity, taste, and sediment. The worst consequences of quality changes are deterioration of water microbiological and chemical parameters, which may be hazardous to human health.

The main source of water in Poland is underground wells. The water from these wells is characterized by a high content of carbonates, bicarbonates, and calcium salts. The high concentration of dissolved minerals, primarily calcium and magnesium ions, increases hardness. In Poland, the total water hardness should not be less than 60 mg CaCO₃/dm³ and not more than 500 mg CaCO₃/dm³ (Regulation 2026). It is excessive water hardness that is one of the major problems for consumers. It forms scale on appliances, such as kettles, coffee machines, and washing machines, as well as deposits on fixtures. To improve the quality of tap

water, consumers use jug filters as a simple home remedy for reducing water hardness.

There are many types of jug filters available on the market. Some are designed solely to eliminate water hardness, but others are designed to raise the water's pH and to enrich it with magnesium ions. There are also filters for very hard water, which have enhanced softening properties. A filter cartridge typically includes activated carbon and ion exchange resin. Activated carbon removes chlorine and organic compounds, while ion exchange resin reduces hardness and heavy metal concentrations. Cartridges may contain a mixture of these ingredients, or they may be layered (Figure 1). The content of filter components can vary, depending on the filter's intended use. Selected filter models contain mineralizing additives designed to enrich the water with valuable elements.

The aim of this study was to determine the effectiveness of jug filtration in softening hard tap water as well as to determine changes in the concentration of calcium and magnesium ions. Additionally, water pH was compared.

MATERIAL AND METHODS

Six filter cartridges from leading manufacturers, placed in dedicated jugs, were used for the study. Before taking measurements, the jugs were washed, filled with cold water, the filter was immersed, and shaken in order to remove air from it.

Additionally, the first two portions of water were filtered and discarded to remove loose filter media and stabilize the filtration process. The filter cartridges are marked with letters A to F. Filters A and E are standard filters, filters B and F are designed for enhanced water hardness removal, filter C is intended to enrich the water with magnesium ions, whereas filter D is intended to increase the water's pH. All analyzed filters had a capacity of up to 150 dm³. The filter media type and application are presented in Table 1.

The tests were performed on tap water collected from an intake point situated on the first floor of the building of the Faculty of Environmental and Energy Engineering at Lublin University of Technology. The tap water sample was collected on the same day on which the analyses were conducted. To make sure the sample was representative, the installation was flushed by draining approximately 30 dm³ of tap water before sampling.

The physicochemical parameters of the tap water drawn from the collection point were as follows:

- temperature: 13–18 °C,
- total hardness: 394 mg CaCO₃/dm³,
- pH: 7.05,
- conductivity EC: 731 µS/cm,
- concentration of Mg: 16.99 mg/dm³,
- concentration of Ca: 106.24 mg/dm³.

The tests began after the initial preparation of filter cartridges according to the manufacturer's

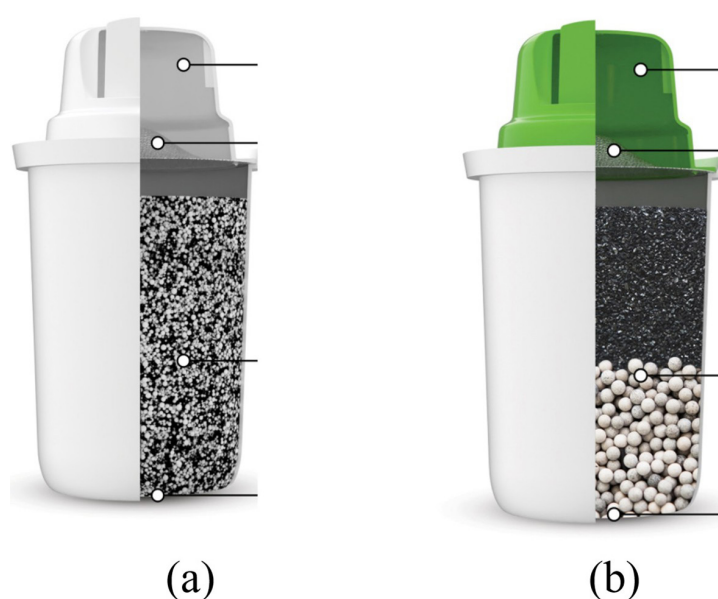


Figure 1. Cross-section of filter inserts: a) mixture of components, b) components arranged in layers
Source: <https://dafi.pl>

Table 1. Characteristics of filter cartridges

Filter	Structure	Application
A	Filter mesh, a mixture of activated carbon and ion exchange resin, the bottom cover with a microporous structure performs repeated mechanical filtration	Removes water hardness and some heavy metals; reduces chlorine and organic compounds
B	Filter mesh, a mixture of activated carbon and an increased amount of ion exchange resin, the lower cover with a microporous structure performs repeated mechanical filtration	Increased softening properties; aimed at reducing calcium and magnesium salts; reduces the content of heavy metals, of chlorine compounds and organic compounds
C	Filter mesh, a mixture of activated carbon and magnesium ion exchange resin, the lower cover with a microporous structure performs repeated mechanical filtration	Enriches water with magnesium ions; does not reduce excessive water hardness; reduces the content of heavy metals, of chlorine compounds and organic compounds
D	Filter mesh, activated carbon and alkaline bed arranged in layers, the lower cover with a microporous structure performs repeated mechanical filtration	Increases the pH of the water and gives it a negative oxidation-reduction potential; does not remove minerals contained in the water; reduces the content of heavy metals, of chlorine compounds and organic compounds
E	Very fine filter mesh, natural coconut shell microcarbon, ion exchange resin, additional high-performance filter mesh	Removes water hardness; reduces chlorine, lead and copper
F	Very fine filter mesh, natural coconut shell microcarbon, increased ion exchange resin content, additional high-performance filter mesh	Increased softening properties; reduces chlorine, lead and copper

Note: Websites of water filter cartridges manufacturers.

recommendations. A total of 150 dm³ of tap water was passed through each of the six tested cartridges, 1 dm³ of water was filtered at a time. Next, the filtered water batch was mixed, and 200 ml was collected with a pipette to determine the hardness of water, while 40 ml was taken for elemental analysis – Ca and Mg. Subsequently, pH and EC measurements were performed on the remaining water. Immediately after filtering a batch and taking a sample for analysis, the next batch was filtered.

To precisely track the dynamics of changes in physicochemical properties during the exploitation of the filter, samples were collected for analysis at variable frequencies, depending on the filtration stage. The sampling scheme was as follows:

- sampling every 1 dm³ until a volume of 5 dm³ of filtered water is reached,
- sampling every 5 dm³ until a volume of 50 dm³ of filtered water is reached,
- sampling every 50 dm³ until the final volume of 150 dm³ is filtered.

Each filtered water sample and tap water were assayed for the following parameters: total hardness, pH, conductivity, and concentration of magnesium and calcium. Analyses were performed at the Environmental Analysis Laboratory of the Faculty of Environmental and Energy Engineering, Lublin University of Technology. A PH-3508

multi-parameter portable meter was used to determine the pH and conductivity of water. To ensure the reliability of the results obtained, the device underwent a two-point calibration before taking measurements. Buffer solutions with values of 6.86 and 4.02 were used, each prepared by dissolving the factory-made solid reagents in 100 ml of water. Total water hardness was determined by titration using EDTA solution in an alkaline medium against Eriochrome black T, in accordance with the PN-ISO 6059:1999 standard. The concentrations of magnesium and calcium were determined using an inductively coupled plasma mass spectrometer – Agilent 8900 ICP-MS Triple Quad. Water samples received for elemental analysis were acidified by adding 0.4 ml of concentrated nitric acid (69–70% Romil Super Purity Acid) and were stored in the dark. The elements were analyzed in He mode (helium flow of 5.5 ml/min). The plasma operated in general-purpose mode with an RF power of 1.550 kW; the nebulizer gas flow was 1.07 l/min, the auxiliary gas flow was 0.9 l/min, and the plasma gas flow was 15 l/min. For the analysis the ISTD internal standard (Sc, Y, Lu) at a concentration of 0.5 ppm was used. The recoveries obtained ranged from 80% to 120%.

Data quality control for selected validation parameters is as follows:

- Mg: calibration curve formula: $y = 0.263x + 5.371$,
- coefficient of determination: $R^2 0.9998$,
- limit of quantification: $LOQ = 0.011622 \text{ mg/dm}^3$,
- Ca: calibration curve formula: $y = 5.174x + 0.0001104$,
- coefficient of determination: $R^2 0.9996$,
- limit of quantification: $LOQ = 0.0017658 \text{ mg/dm}^3$.

Hardness removal efficiency was calculated using the Equation 1:

$$\text{removal efficiency} = \frac{(C_i - C_f)}{C_i} \cdot 100\% \quad (1)$$

where: C_i and C_f are the initial and final hardness in $\text{mgCaCO}_3/\text{dm}^3$, respectively.

RESULTS AND DISCUSSION

High water hardness is unacceptable to consumers. It builds up scale on household appliances and dries out the skin. Consequently, they resort to home water softening methods. In Poland, the total water hardness should not be less than $60 \text{ mgCaCO}_3/\text{dm}^3$ and not more than $500 \text{ mgCaCO}_3/\text{dm}^3$ (Regulation 2026). The primary purpose of jug filters is to remove water hardness. Studies (Figure 2) have shown that in the initial filtration phase, all filters except D significantly softened the water. Filter B reduced the water hardness below the level required by the regulation. This could be due to the filter being designed for very hard water, which has the ability to remove more calcium and magnesium ions; the tap water is considered hard in the hardness scale. Filter C reduced water hardness during the initial filtration phase, despite the manufacturer's claim that it does not. However, after

15 dm^3 of water had been filtered, the hardness returned to its initial level. Filter D slightly increased the overall hardness of the tap water, despite the manufacturer's claim that it does not change it.

Filter A achieved efficiency above 50% when filtering up to 5 dm^3 of water, and then its efficiency decreased, reaching only 11% after filtering 150 dm^3 of water. The average efficiency of this filter for the entire filtration process was 33%. Filter B achieved an efficiency above 50% after filtering 10 dm^3 of water, then its efficiency dropped drastically. After filtering 20 dm^3 of water, its efficiency was below 20%. According to the manufacturer, this filter was supposed to have improved water hardness removal properties. According to the manufacturer, filters C and D should not reduce water hardness, but filter C achieved an average efficiency of 29% before the first 5 dm^3 . Filter E achieved an efficiency above 50% after filtering 4 dm^3 of water. Its efficiency then decreased to an average of 35% throughout the entire water filtration process. Filter F proved to be the most effective. Its efficiency exceeded 50% after filtering 20 dm^3 of water, and it remained high. After filtering 150 dm^3 of water, its average efficiency was 46%. This filter is intended for hard water.

Similar results were obtained by Puszczalo et al. (2020, 2021), Kamińska et al. (2022), Domoń et al. (2024), and Piaskowski et al. (2025). In their studies, water hardness also decreased in the initial stage of filtration, and then it increased.

When analyzing the pH values of filtered water (Figure 3) in relation to tap water (pH 7.05), it should be noted that, during the initial filtration stage, filters A, B, E, and F lowered the pH below the minimum value of 6.5, required by the Regulation (2026). Filters E and F maintained this lowered value up to 30 dm^3 of filtered water.

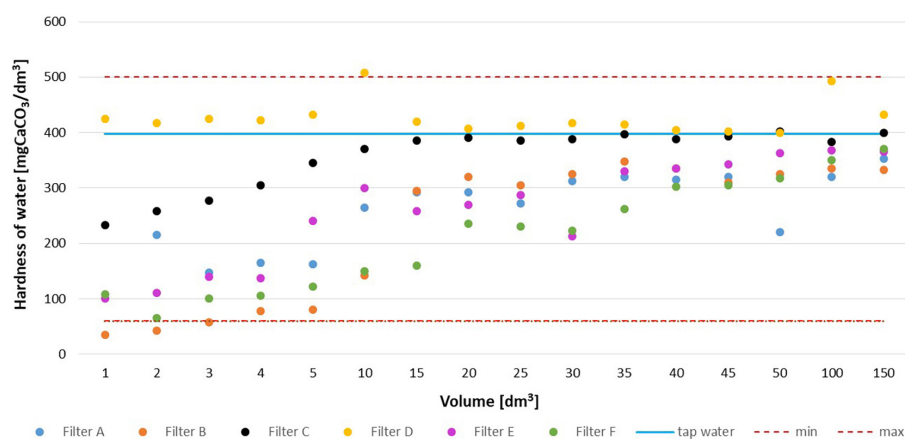


Figure 2. Changes in tap water hardness during jug filtration using A-F cartridges

Filter C slightly increased the water pH, probably due to the use of magnesium ion exchange resin. Filter D, which is designed to raise the water pH by using an additional alkaline resin, raised this parameter to 8.5, and then gradually lowered it. However, throughout the filtration period, the pH did not approach the initial value and remained at approximately 7.5. None of the filters raised the water pH above the maximum level required by the Regulation, i.e. pH 9.5.

It should be noted that consuming water with a pH lower than 6.5 may contribute to poor health. Drinking acidic water irritates the gastric mucosa, contributing to heartburn and reflux (Dewangan 2023, Arhin 2024). It may also cause an imbalance in mineral levels in the body (Zalvan 2017, Helte 2022).

Changes in water mineralization are presented using conductivity (Figure 4). This parameter makes it possible to assess the dissolved ion content in water. The higher the conductivity value, the higher the concentration of dissociated ions. Most filters reduced water mineralization throughout the filtration process. Filters C and D maintained conductivity similar to the tap water. This may be due to the different composition of the filter material.

Water conductivity is related to water hardness. Hard water has higher conductivity because it contains more calcium and magnesium ions. Studies indicate that excessive removal of magnesium ions from water can cause coronary heart disease and stroke (Helte 2022, Bykowska-Derda 2023). The studies conducted (Figure 5) show that in the initial filtration phase, the magnesium ion content dropped

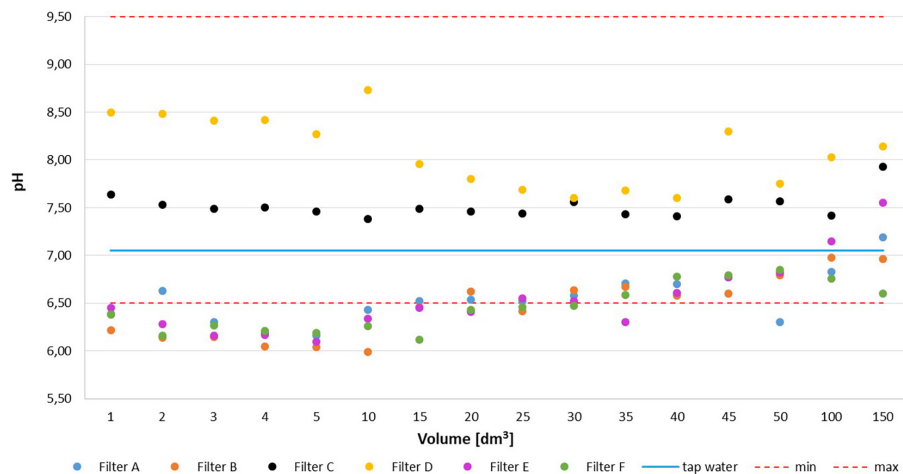


Figure 3. Changes in pH of tap water during jug filtration using A-F cartridges

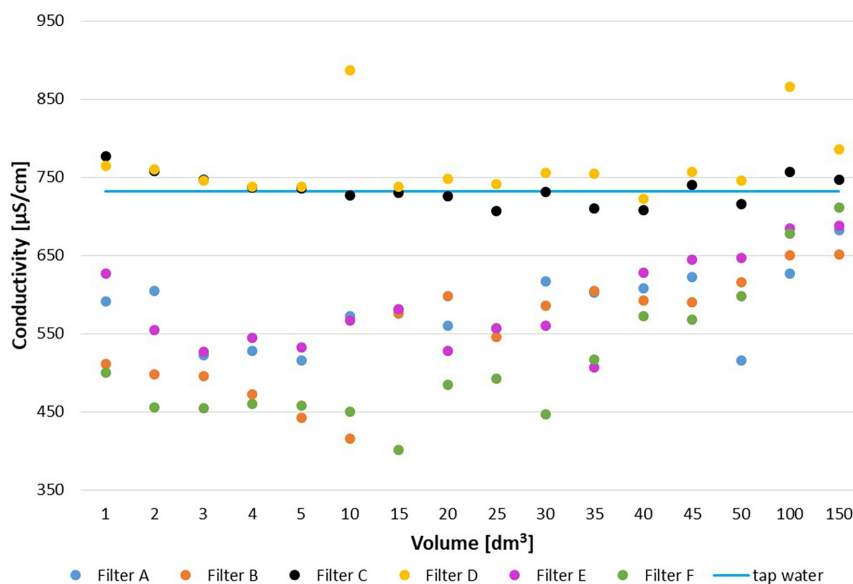


Figure 4. Conductivity changes of tap water during jug filtration using the A-F cartridges

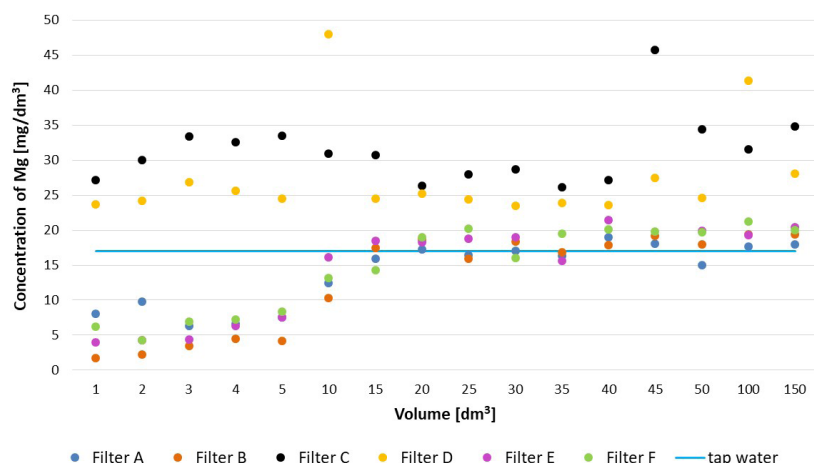


Figure 5. Concentration of magnesium changes in tap water during jug filtration using A-F cartridges

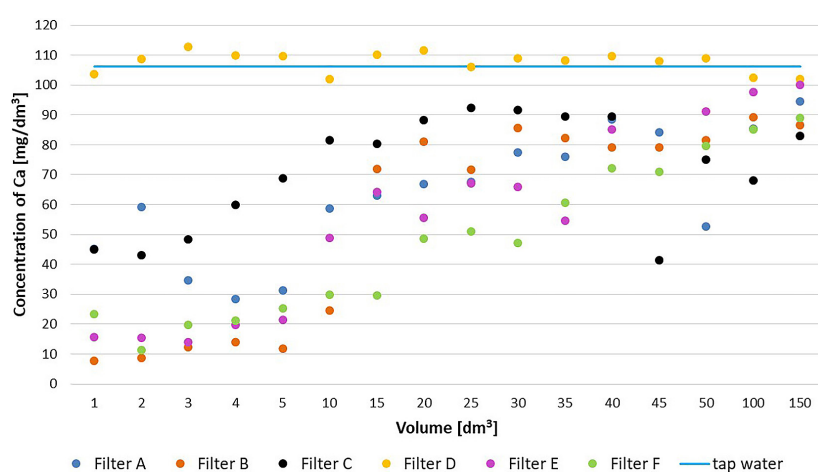


Figure 6. Concentration of calcium changes of tap water during jug filtration using the A-F cartridges

significantly (to 15 dm³), and then the magnesium concentration returned to a value comparable to that of the tap water. The exceptions are filters C and D, which are designed to enrich the water with magnesium (C) or not remove minerals from the water (D). Both filters increased the magnesium concentration throughout the filtration process.

Changes in calcium concentration during the filtration process are shown in Figure 6. All analyzed filters (except D) reduced the calcium ion concentration in the filtered water during the initial filtration stage. After approximately 10 dm³ of water had been filtered, the calcium removal efficiency decreased significantly. Only filter D did not remove calcium ions. It should be noted that it also did not change the overall hardness of the filtered water.

Similar results were obtained by Kwiakowski et al. (Kwiakowski 2024) and Hazzazi et al. (Hazzazi 2025). While analyzing changes in calcium and magnesium ion concentrations in jug

filters, they noted that filter efficiency was higher only at the initial stage of filtration; after filtering 15 dm³ of water, the concentrations of these ions were comparable to those in tap water.

CONCLUSIONS

Studies have shown that the effectiveness of jug filtration in water softening is high only in the initial stage of the process, and it decreases significantly over time. A decrease in water hardness below the value recommended by the Regulation – 60 mg CaCO₃/dm³ is unfavorable, as it leads to an almost complete removal of calcium and magnesium ions from the water. In the case of very hard water, due to faster filter cartridge wear, it is advisable to replace filter cartridges more frequently than the manufacturer recommends. When the decrease in water hardness is

considered, it can be seen that filters A, E, and F proved most effective. They did not cause hardness to drop below the permitted values, and they softened the water throughout the filter's life.

When analyzing the pH parameter, it should be noted that only filters C and D did not cause the pH to drop below the norm, i.e. pH 6,5 according to the Regulation. Water with an acidic pH should not be consumed. According to the conducted research, the first 15 dm³ of water filtered through filters A, B, E, and F should be discarded or used for other purposes, such as watering plants.

Considering the conductivity of water, which depends on the amount of dissolved mineral ions, only filters C and D showed unchanged conductivity. This was due to the different composition of the filter mixture. This is clearly visible when analyzing the graphs of changes in magnesium and calcium concentrations in the filtered water. Filter C removed calcium ions and enriched the water with magnesium ions, while filter D did not change the calcium concentration in the filtered water and slightly increased the magnesium concentration.

REFERENCES

- Arhin, E., Osei, J.D., Anima, P.A., Afari, P.D., Yevugah, L.L. (2024). The pH of drinking water and its human health implications: A case of surrounding communities in the Dormaa central municipality of Ghana. *Journal Healthcare Treatment Development (JHTD)*, 4(1), 12–22. <https://doi.org/10.55529/jhtd.41.15.26>
- Bykowska-Derda, A., Spychala, M., Czlapka-Matyasik, M., Sojka, M., Bykowski, J., Ptak, M. (2023). The relationship between mortality from cardiovascular diseases and total drinking water hardness: Systematic review with meta-analysis. *Foods*, 12(17), 3255. <https://doi.org/10.3390/foods12173255>
- Dewangan S.K., Shrivastava S.K., Tigga V., Lakra M., Preeti N. (2023). Review paper on the role of pH in water quality implications for aquatic life, human health, and environmental sustainability, *Int. Adv. Res J. Sci., Eng. and Technol.*, 10(6), 215–218. <https://doi.org/10.17148/IARJSET.2023.10633>
- Domón, A., Papciak, D., Sočo, E. (2024). Clean and Tasty Water - Analysis of the Effectiveness of Water Filter Jugs. In: Blikharsky, Z., Koszelnik, P., Lichołai, L., Nazarko, P., Katunský, D. (eds) *Proceedings of CEE 2023. CEE 2023. Lecture Notes in Civil Engineering*, 38. Springer, Cham. DOI: https://doi.org/10.1007/978-3-031-44955-0_12
- Hazzazi, L.W., Soto-Rojas, A.E., Martinez-Mier, E.A., Nassar, H.M., Eckert, G.J., Lippert, F. (2025). The effect of water filter pitchers on the mineral concentration of tap water. *J Public Health Dent.*, 85(1), 21–28. <https://doi.org/10.1111/jphd.12649>
- Helte, E., Säve-Söderbergh, M., Larsson, S.C., Åkesson, A. (2022). Calcium and magnesium in drinking water and risk of myocardial infarction and stroke – a population-based cohort study. *The American Journal of Clinical Nutrition*, 116(4), 1091–1100. <https://doi.org/10.1093/ajcn/nqac186>
- Jachimowski, A. (2017). Factors affecting water quality in a water supply network. *Journal of Ecological Engineering*, 18(4), 110–117. <https://doi.org/10.12911/22998993/74288>
- Kamińska, G., Puszczalo, E., Marszałek, A. (2022). Performance of jug filtration in tap water softening and chlorine removal. *Polish Journal of Materials and Environmental Engineering*, 4, 13–20. <https://doi.org/10.53052/pjmee.2022.4.02>
- Kwiatkowski, H., Kreft, K., Ronda, O., Cieślík, B.M. (2024). The effect of using jug-type water filters on selected metals concentration in tap water – a case study. *J Water Health*, 22(7), 1261–1270. <https://doi.org/10.2166/wh.2024.071>
- Piaskowski, K., Stanisławska E. (2025). The importance of drinking water hardness and its removal in home water purification systems. *Gas, Water and Sanitary Technology*, 9, 16–21. (in Polish) <https://gazwoda.pl/doi-10-15199-17-2025-9-3/>
- Puszczalo, E., Kudlek, E., Marszałek, A. (2020). Assessment of the possibility of secondary water pollution during its purification in filtering jugs. *Desalination and Water Treatment*, 186, 290–296. <https://doi.org/10.5004/dwt.2020.25333>
- Puszczalo, E., Marszałek, A., Kamińska, G. (2021). Application of jug filters for the treatment of model well water. *Desalination and Water Treatment*, 242, 31–37. <https://doi.org/10.5004/dwt.2021.27846>
- Regulation of the Minister of Health of May 22, 2026, on the quality of water intended for human consumption (in Polish).
- Wang, Z., Yang, X., Fu, L., Li, M. (2025). A review of secondary contamination of drinking water quality in distribution systems: sources, mechanisms, and prospects. *AQUA - Water Infrastructure, Eco-systems and Society*, 74(1), 118–141. <https://doi.org/10.2166/aqua.2024.284>
- Zalvan, C.H., Hu, S., Greenberg, B., Geliebter, J. (2017). A comparison of alkaline water and mediterranean diet vs proton pump inhibition for treatment of laryngopharyngeal reflux. *JAMA Otolaryngology: Head & Neck Surgery*, 143, 1023–1029. <https://doi.org/10.1001/jamaoto.2017.1454>