

The influence of minerals on water filtration effectiveness

Delila Lekić and Altijana Hromić-Jahjefendić*

Department of Genetics and Bioengineering, International University of Sarajevo, Bosnia and Herzegovina

*Corresponding author: ahromic@ius.edu.ba

Received Nov. 3, 2023

Revised Nov. 7, 2023

Accepted Nov. 15, 2023

Abstract

Water is necessary for every organism since almost every cell process would be jeopardized if the body lacked water. The issue is that drinkable water needs to be processed and filtered to be purified enough and should not contain any pathogens. In this study, the focus was on the filtration of minerals like active carbon, alunite, and pyrophyllite with a focus on their antibacterial properties. What this study has shown is that the usage of minerals with antibacterial properties could potentially aid people and avoid large consumption of antibiotics. The world-known active carbon as a drinkable water filter proved to be quite efficient in lowering the number of colonies on each plate. However, pyrophyllite and alunite also proved to be efficient when it comes to antibacterial properties. The study offers multiple possibilities for further research as well, like expanding the number of minerals or the number of samples and concentrations or expanding the study to the synergy of said minerals. Since both alunite and active carbon can be consumed orally and the chances of people having serious consequences if they are present in water are pretty small, there is yet to be proven if pyrophyllite poses a threat to the human body if ingested.

© The Author 2023.

Published by ARDA.

Keywords: Water filtration, Alunite, Pyrophyllite, Active charcoal, CFU

1. Introduction

Clean drinking water and proper sanitation are basic human rights. However, despite the World Health Organization establishing this statement as a norm, there are still places around the world that do not have access to clean water and are forced to consume contaminated water leading to numerous diseases including diseases of the gastrointestinal tract, respiratory infections, and even an increase in tropical disease prevalence [1]. Based on these facts, the aim of this study was to investigate naturally occurring elements that are eco-friendly, easily accessible, easy to use and incorporate into water filtration systems to minimize the impact of microbiologically contaminated waters.

1.1 Activated carbon

1.1.1 Basic properties

Active carbon or activated charcoal is a type of material that is very carbon-rich and is usually made of either wood, bamboo, coal, or other materials. There are two different ways in which activated carbon is made,

This work is licensed under a [Creative Commons Attribution License](https://creativecommons.org/licenses/by/4.0/) (<https://creativecommons.org/licenses/by/4.0/>) that allows others to share and adapt the material for any purpose (even commercially), in any medium with an acknowledgement of the work's authorship and initial publication in this journal.



physical and chemical activation [2]. The most efficient way is to expose the material to anaerobic conditions under very high temperatures ranging from 600 – 900 degrees Celsius, after which it is exposed to argon or nitrogen and subjected to yet another series of very high temperatures this time ranging from 600 – 1200 degrees Celsius and with the presence of oxygen, the characteristic porous structure is formed [3]. This process is known as pyrolysis of, usually, biomass since it is the most environmentally friendly and sustainable material. In chemical activation, zinc chloride (ZnCl_2), potassium hydroxide (KOH), sodium hydroxide (NaOH), phosphoric acid (H_3PO_4), etc. are used and carbonization follows at temperatures between 400 – 800 degrees Celsius [2]. The structure of the pores within active carbon can be seen under an electron microscope and showed that the material, microscopically, possesses a honeycomb surface. Based on these findings, scientists were able to calculate that 0.4kg of this material can have almost 0.4 km^2 of surface area within. The pores are small and have low volume which contribute to its increased adsorption capacities hence why it is often used in filtrations, cleaning, deodorizing or various medical applications because the contaminants can bind to its surface and remain trapped in the microstructure [4].

1.1.2 Active carbon in water filtration

The reason for a strong interaction between the pores of activated carbon and the contaminant/pollutant are the London dispersion forces or Van der Waals interactions [5]. With the addition of chemicals, such as sulfur, KOH, H_3PO_4 , the interaction between active carbon and the pollutant becomes even stronger hence why industrially speaking it would pose an even better solution.

Active carbon can come in two different forms when it comes to filtration, either PAC (powdered activated carbon) or GAC (granular activated carbon) [4]. PAC filtration consists of active carbon grounded into very small particles that are removed from the solution after the filtration, while GAC contains larger particles and larger surface area which means that it is more often used as a particle remover that is placed downstream of the water that is supposed to be filtered. One of the main disadvantages of these filters is the microbial growth around the filters that concerned scientists about the potential health hazard [6]. While most of the activated carbon filters are used in water treatment plants to remove chemicals and odor from industrial wastewaters, scientists proposed that active carbon could also potentially be used as a microbiological filter in a different manner known as BAC (beads-packed activated carbon). However, studies have shown that it did not have a significant impact on the growth of microorganisms in means of lowering the microbial growth [7]. In another study, it was proposed that active carbon filters could potentially lead to an increase in microbial population since the basis of the mechanism is that carbon causes the decay of chlorine and, while it destroys the surface chlorine, it leaves the rest intact thus turning the surface very favorable for microorganisms [8]. However, this theory heavily depends on which microorganisms are present in the solution. On the other hand, another study done on the effects of activated charcoal in water filtration has shown that active carbon filters like “Brita” show good quality water filtration even after the expiration date and ensure that the water is safe for drinking [9].

1.2 Alunite

1.2.1 Basic properties

Alunite is a type of mineral that comes in various colors starting from colorless or translucent to red or yellow, and is closely related to gypsum, quartz and pyrite. Its chemical composition is potassium aluminum sulfate dodecahydrate ($\text{KAl}_3(\text{SO}_4)_2(\text{OH})_6$) [10] and it found its application in multiple branches like water purification, deodorizing, dyeing, it can also be used as an after shave etc. [11], [12]. Alunite has been used for a long time considering that even the Roman army doctor in his book “De Materia Medica” has talked about its healing properties and usefulness in closing minor wounds since it is astringent, as well as treating ulcers and various skin conditions [13], [14]. And as a deodorant, it has shown to have antibacterial properties as well [13]. Having said that, it is only logical to assume that consuming alunite as a solution could lead to certain health

improvements. However, there are no specific studies done to confirm this statement. But, it has been stated that certain communities have used it as a prevention of cold or cold sores inside the oral cavity. Drinking an alunite solution in different concentrations depending on the severity of the cause, could potentially have its benefits like aiding in different digestive system issues whether it is minor hemorrhage or constipation, vertigo, heart palpitations, muscle weakness, etc. [15]. There are also disadvantages of consuming alunite, a concentration too large could lead to stomach pains and digestive issues like diarrhea or vomiting, possibly because of its high aluminum concentrations.

1.2.2 Alunite in water filtration

There are not many studies done on the potential of alunite in water filtration. Although, some studies confirm that it is quite effective in removing phosphate and its by-products in water [16]. However, alunite is used in the production of alum which is a large group of hydrated aluminum sulphate salt compounds that can be used in numerous industries based on which metal is added to it [17]. Based on that metal, alum changes both colors and properties, for example: chrome alum has a deep purple color and is used in tanning but combined with another alum, it can grow beautiful purple crystals; potassium alum is used in water purification, sodium alum is used in vegetable pickling, etc. [17]. Alum is also used in clarifying muddy water because: “alum treatment removes a good proportion of pathogens and subsequently makes simple disinfection procedures possible” [18]. Various studies have been conducted to test the antimicrobial properties of alum. In one of the studies, alum was tested against *Proteus mirabilis*, and it has been shown that different concentrations affect microbial motility in culture [19]. In other studies, alum also proved to be quite efficient against different bacterial strains like *S. aureus*, *S. epidermidis*, as well as yeast found in mouth lesions [19]. However, more studies are yet to be conducted to find the absolute potential of alum as an antimicrobial agent. Several more studies have been conducted on animal models to discover more possibilities of potash alum and it has been shown that it could potentially be used as a treatment for aggregation of platelets and obesity since it lowers the number of total cholesterol and high – density lipoproteins in blood [19]. Having named all of the benefits of alum, the possible side effects of ingesting a large concentration of potassium alum include upset stomach with diarrhea and vomiting, eye irritation if it comes in contact, impaired kidney function in cases of very high doses [20]. Another possible disadvantage of alum, as mentioned before, due to the high aluminum concentrations a correlation between aluminum and breast cancer has been found and using alum as a deodorant for a prolonged period of time could potentially aid the cause. But this claim has not been researched enough yet [20].

1.3 Pyrophyllite

1.3.1 Basic properties

Pyrophyllite ($\text{Al}_2\text{Si}_4\text{O}_{10}(\text{OH})_2$) is a hydrous aluminum silicate mineral that displays unique properties desirable by multiple different industries such as cosmetics, pharmaceutical and medical industries, production of paper, pesticides, fertilizers, etc. Although, in order to be applicable, it should be stripped from any impurities like titanium or iron since their presence greatly alter its properties [21]. As a result, certain industries require these impurities to be only in trace amounts. The purification can be done using the EDTA leaching procedure. EDTA leaching procedure is based on the fact that it binds to metals and forms complexes, and it also has a higher affinity for transition metal atoms and ligands such as cobalt, nickel, molybdenum, and vanadium [22]. Its properties are the most similar to talc, feldspar or kaolinite and it can be used instead of these minerals [21]. There are a few other points that need to be taken into consideration, like increasing its market value by adding aluminum oxide or Al_2O_3 . Due to its unique properties, pyrophyllite can also be used in refractory industry in multiple different forms, for example when it is converted into mullite it can withstand very high temperatures up to 1810 degrees Celsius. It can also be crushed and combined with other materials like sodium silicate, fireclay, zirconia, and then used to produce tiles, cement – fired bricks, and other special refractories [21]. It can

also be used as a filler in other industries like paper, plastic, paint, and soil conditioner. In ceramics industry, pyrophyllite powder is important due to its low expansion when it is heated and stability in high temperatures [23].

1.3.2 Pyrophyllite in water filtration

Because of its unique adsorption properties, pyrophyllite can be used as a filter for industrial wastewaters since it can bind toxic metals, chemicals like fluoride, phenol, cyanide, other inorganic pollutants as well as issues with microbiological contamination [24]. However, pure and high quality pyrophyllite is rarely found in nature hence why most companies use modified pyrophyllite [24]. Pyrophyllite can be modified in various ways depending on the necessity, like for example the addition of prehydrolyzed APEO (N-(2-aminoethyl)-3-aminopropyltrimethoxysilane) for the removal of nitrophenol in water [25]. It has been proven that pyrophyllite can also be used to remove ammonia compounds in water, as well as iron, nickel and manganese [26]. In another study, pyrophyllite clay proved to be quite effective in removal of fluoride from the solution [27].

The purpose of this study is to observe the effect of above-mentioned minerals in water filtration process through microbiological growth.

2. Research method

2.1 Preparation of the plates

The method that was used to make the Luria – Bertani (LB) medium included the combination of 12.5 mL of premade LB broth, 7.5 mL of agar and 480 mL of distilled water. All of the bottles were autoclaved on program 4 for liquids at 121°C for about 1 hour. After all the bottles were cooled down at room temperature, they were poured into Petri dishes and allowed to sit at room temperature overnight after which they were transferred to the fridge at 4°C. It is important to mention that this whole process was done under nearly sterile conditions, the hood was kept disinfected at all times as was all the equipment that was used. In order to be able to fully compare the efficiency of filtration with minerals when it comes to lowering the number of microbial colonies, plates with an antibiotic were also used as a control. 500 µL of 1M ampicillin was added to 500 mL of LB broth with agar. Out of 117 plates, the total number of antibiotic plates was 54 and the non-antibiotic ones was 63. The difference in number of plates is due to yet another control which was fully untreated water.

2.2 Acquiring the water samples

Three different water samples were used: tap water from the laboratory, bottled water “Oaza” bought in “Konzum” market in Sarajevo, Bosnia and Herzegovina, and a river sample from Željeznica. The river sample was possibly the one that was the most intriguing since the river is usually very muddy, has lots of garbage and is used as a reservoir for sulfur rich water from a nearby thermal resort. The sample was acquired from a place where people are usually swimming or fishing, and the thermal pool of water is in close proximity.

2.3 Filtration

The water filtration process was again done under nearly sterile conditions where the equipment and surrounding surfaces were disinfected beforehand. Two different amounts of each mineral were used, 1g and 5g. The process was the following: A funnel was placed in an Erlenmeyer flask along with a single filter paper. 1g or 5g of pre-weighed powdered mineral was added to a different flask along with 100 mL of the first water sample to ensure complete dissolving after which the solution was poured into the filter paper through the funnel. The process was repeated for every mineral amount and water sample, respectively. The activated carbon was purchased from BM Logistic d.o.o. in Sarajevo (Bosnia and Herzegovina). Pyrophyllite was obtained from the AD HARBI

d.o.o. company exploiting the mineral from Parsovići-Konjic (Bosna and Hercegovina). Alunite mineral was obtained from the pharmacy shop in Sarajevo (Bosnia and Herzegovina).

2.4 Cultivation of the microorganisms

Cultivation of the microorganisms was done using the spread plate method [28] and followed the water filtration. When all the plates were labeled, the first 3 plates to be inoculated were the ones with the untreated water. Once the sample was filtered, 200 µL of that sample were added to the corresponding Petri dish and spread over the agar using a glass spreader. 3 of those plates contained an antibiotic, 3 did not. The plates were incubated at 37°C for two days. This process was repeated until all the plates were inoculated.

3. Results

Table 1: Comparison of CFU (colony forming units) obtained before and after filtration

	Tap water			Bottled water			River water		
	1	2	3	1	2	3	1	2	3
Control	7	0	0	20	8+	7+	120+	130+	101+
Active carbon 1g	1	0	0	1	3	5	55+	66+	55+
Antibiotic	0	0	0	0	0	0	5	0	0
Active carbon 5g	1	1	0	1	1	0	5	23	80+
Antibiotic	0	0	0	0	0	0	0	0	0
Alunite 1g	0	0	0	1	0	0	100+	120+	94
Antibiotic	0	0	0	0	0	0	0	0	0
Alunite 5g	0	0	0	0	0	0	140+	3;180+	172+
Antibiotic	0	0	0	3	0	0	0	0	0
Pyrophyllite 1g	1	0	0	5	0	0	36+	14+	47+
Antibiotic	0	0	0	0	0	0	0	0	0
Pyrophyllite 5g	1	0	0	0	0	0	80	4;19	4;2;3
Antibiotic	0	0	0	0	0	0	0	0	0

3.1 Tap water

From the Table 1, we can see that 1 control had 7 colonies while the rest did not have any. These results could be due to cross contamination; however, it did not affect the rest of the plates that were cultivated one after another. As for the minerals, active carbon and pyrophyllite proved to be quite efficient with lowering the number of colonies from 7 to 1. Although, alunite was the most effective mineral in this case since all the plates were clean and had no colonies. The clean antibiotic plates show us that the bacteria present were in fact, not antibiotic resistant. In comparison, all of the minerals (with respect to alunite) proved to be almost as effective as an antibiotic.

3.2 Bottled water

Surprisingly, bottled water was more contaminated than the tap water. We can clearly see that all 3 controls had microbial growth ranging from 7 – 8 to 20 colonies per plate. Granted, most of those colonies were quite large as well and had numerous punctiform colonies around them. When it comes to active carbon, it proved to be more efficient in concentration of 5g opposed to 1g, but it still lowered the number of colonies quite well. Alunite, on the other hand, in both concentrations had barely any or no colonies on the plate (opposed to one

that could just be cross contamination). This time, there were 3 punctiform pink colonies on one of the antibiotic plates that cannot be explained. If it were antibiotic resistant bacteria, granted it would be shown on other plates as well. Pyrophyllite, however, proved to be quite efficient by lowering the number of colonies to 5 on one plate only, while 5g of pyrophyllite all had clean plates with no microbial growth.

3.3 River water

This sample sort of showed the real results since the number of colonies on control was quite large, ranging from 100 – 130 large colonies with numerous medium, small and punctiform ones as shown in Figure 1. Active carbon in concentration of 1g managed to lower the number of large colonies by half on all 3 plates and only left a couple of small colonies around them (Figure 2). Meanwhile, in concentration of 5g, one plate had 5 small/punctiform colonies while the rest had 20 and 80+ large colonies, respectively (Figure 3). However, the plate that contained 23 colonies exactly, were mostly small/punctiform with only 3 – 4 large ones. One of the antibiotic plates was also positive with microbial growth which means that it was probably cross contamination of bacteria resistant to antibiotics. If it was not, indeed, a cross contamination, active carbon proved to be as efficient as an antibiotic on the rest of the plates that did not contain colonies.

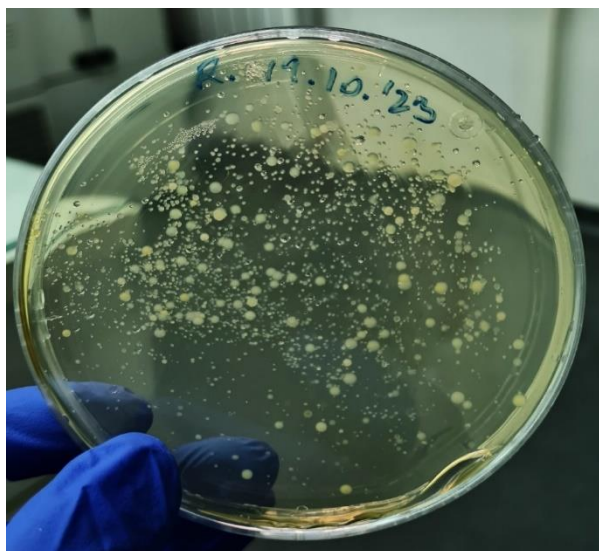


Figure 1. River water control

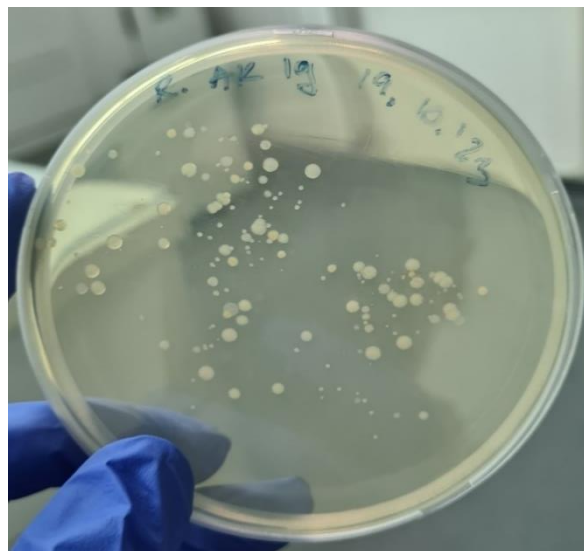


Figure 2. 1g of active carbon in the river water sample

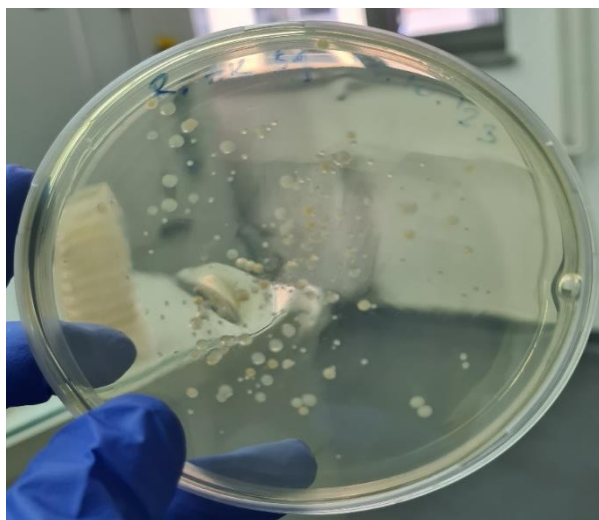


Figure 3. 5g of active carbon in the river water sample

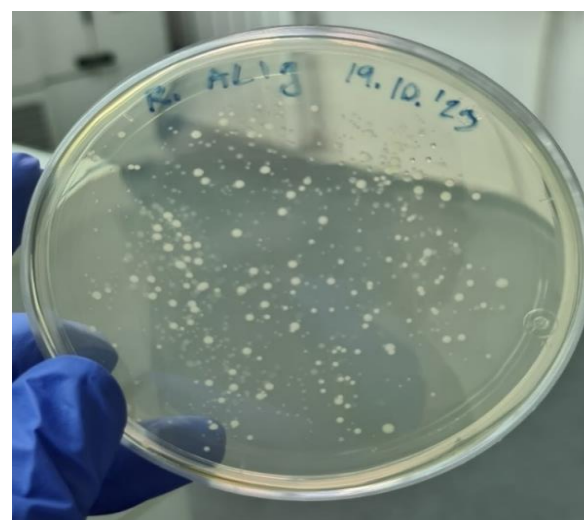


Figure 4. 1g of alunite in the river water sample

When it comes to alunite, in both concentrations it managed to make the size of the colonies smaller, hence why the number of present colonies is much larger than the control. There were definitely less large colonies present on all of the plates and most were medium or small/punctiform.

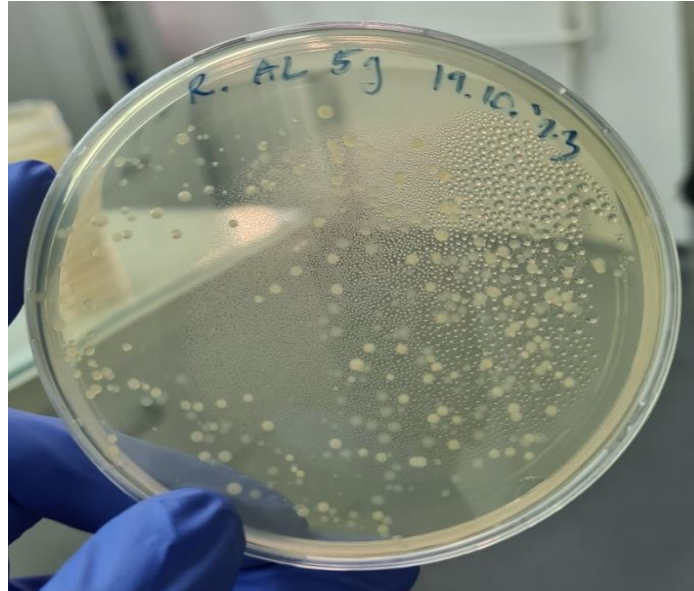


Figure 5. 5g of alunite in the river water sample

Pyrophyllite definitely decreased the number of colonies more than the previous minerals, however, based on the shape and size of the colonies, we could conclude that the microorganism that was present was not the same as on the other plates (possibly yeast) hence why the number is way lower than the previous results. Another fact to support this statement is that the shape of the colonies is different, they were irregular and almost filamentous in some cases. There is a significant difference between 1g and 5g of pyrophyllite because, for example, 5g of pyrophyllite had only 4 (but very large) colonies on both plates and a couple of smaller and medium ones. And, once again, the antibiotic

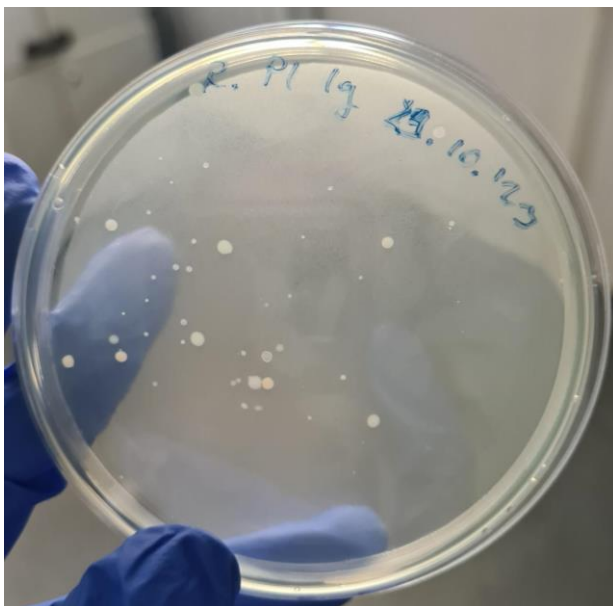


Figure 6. 1g of pyrophyllite in the river water sample

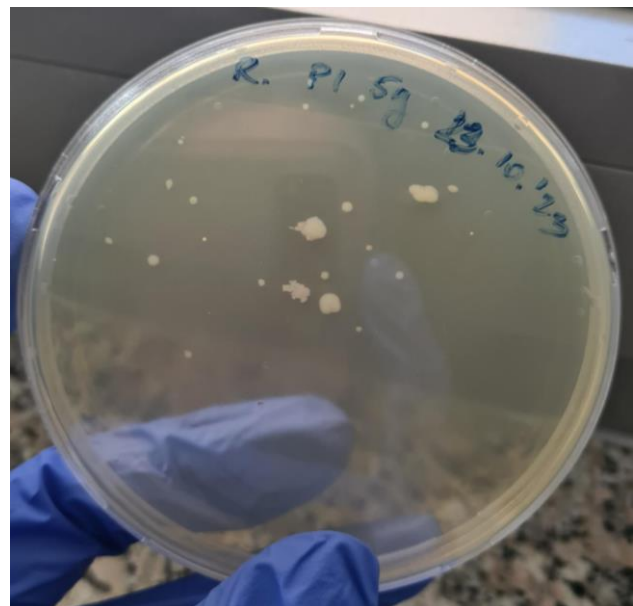


Figure 7. 5g of pyrophyllite in the river water sample

4. Discussion and conclusion

Based on the results that were obtained in the experimental phase, it has been proven that active carbon is, after all, a very good material in water filtration. Maybe if the water was filtered multiple times, it would have decreased the number of colonies even more. However, that is one of the limitations of this study. This statement is backed up by multiple studies and the fact that activated charcoal is one of the most popular materials used in these purposes [4]. Since there is not much literature available online regarding water filtration with alunite, we can discuss obtained results by comparing the potential of alum and different alum variations that were previously mentioned. Alum has been used in water filtration for a long time and it can even turn muddy water into clear, drinkable water because of its potential to eliminate pathogens [18]. By extension, this could also be applied to alunite, the main and starting ingredient of alum. Although, another limitation of this study is the fact that there was no selection regarding microorganisms, and we do not know for sure which strains were found before and after filtration and whether the water was actually safe to drink. When it comes to pyrophyllite, there are multiple studies that confirm its potential in removing toxic metals and chemicals in industrial waters. In this case, it has also been proven that it removes a large number of pathogens as well, proving the main hypothesis of the study. However, even though it has reduced the number of existing colonies, there is a possibility that it had been a brand new microorganism. As stated before, it is a limitation of the study.

To conclude, the purpose of this study was to determine whether or not certain minerals can be used in water filtration and, if so, to determine the efficiency of each of those minerals when it comes to microbiological contamination of drinking waters. The results vary, from lowering the total number of colonies to preventing their growth in terms of the size of each individual colony. It has been found that some active carbon water filters that are consistently used in purifying industrial waters, only enhance the microbial growth as a consequence of the mechanisms used to remove unwanted chemicals and toxic, heavy metals. Hence why a couple of other minerals were used as well even though active carbon proved to be quite effective in lowering the total number of colonies. Alunite was very effective on smaller number of colonies, but in a sample with a larger number it only decreased the colonies in size. Pyrophyllite proved to be quite efficient in lowering the total number of colonies per plate. It is also very sustainable and can be found in abundance, even in Bosnia and Herzegovina. We are yet to prove and determine its effects on the environment and the human body if it were ingested, but even then, it is highly unlikely that it will react in a harmful way towards the ecosystems. All of the minerals that were used have a specific way in which they can be considered antibacterial or antimicrobial, ranging from actually decreasing the total number of colonies to reducing their size individually. This study offers a starting point towards other, possibly new, studies about synergy of the minerals where multiple of them could be used to achieve the best results when their individual characteristics are combined. As mentioned previously, there are a couple of limitations to this study that can be overcome in the new studies, like including industrial wastewaters with different chemicals and toxic metals, increasing the number of samples, documenting the exact strain of microorganism before and after filtration and reducing the possibility of cross contamination even further.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

Funding information

International University of Sarajevo, Bosnia and Herzegovina funded this research.

References

- [1] World Health Organization, “Drinking-water,” <https://www.who.int/news-room/fact-sheets/detail/drinking-water>. Accessed: Nov. 10, 2023 [Online]. Available: <https://www.who.int/news-room/fact-sheets/detail/drinking-water>
- [2] J. M. Illingworth, B. Rand, and P. T. Williams, “Understanding the mechanism of two-step, pyrolysis-alkali chemical activation of fibrous biomass for the production of activated carbon fibre matting,” *Fuel Processing Technology*, vol. 235, p. 107348, 2022
- [3] General Carbon Corporation, “Activated carbon & charcoal frequently asked questions: FAQ page” Accessed: Nov. 10, 2023. [Online]. Available: <https://generalcarbon.com/facts-about-activated-carbon/activated-carbon>
- [4] C. Cavallo, “What is activated carbon and how is it made?” Accessed: Nov. 10, 2023. [Online]. Available: <https://www.thomasnet.com/articles/chemicals/what-is-activated-carbon/>
- [5] Hydrosil International, “Activated Carbon/Charcoal,” Accessed: Nov. 17, 2023. [Online]. <https://hydrosilintl.com/>
- [6] Environmental Information System, “Difference between PAC and GAC,” Accessed: Nov. 17, 2023. [Online]. Available: <https://www.envis.org/technology/water-treatment/687-difference-between-pac-and-gac>
- [7] J. V Fiore and R. A. Babineau, “Effect of an activated carbon filter on the microbial quality of water,” *Appl Environ Microbiol*, vol. 34, no. 5, pp. 541–546, 1977.
- [8] Carbotecnia, “Microbial activity in activated carbon,” Accessed: Nov. 19, 2023. [Online]. Available: <https://www.carbotecnia.info/learning-center/activated-carbon-theory/bacteria-in-activated-carbon/?lang=en>
- [9] A. Hromić- Jahjefendić, S. Kozarić, A. Hrapović, A. Trebo, A. Tipura, and M. Adilović, “Comparison of Brita and Profissimo water filters,” *Heritage and Sustainable Development*, vol. 5, no. 1, pp. 151–158, 2023
- [10] E. W. Team, “Potassium aluminium sulfate dodecahydrate, potassium aluminium sulfate dodecahydrate (CHEBI: 86465). Accessed: Nov. 17, 2023. [Online]. Available: <https://www.ebi.ac.uk/chebi/searchId.do?chebiId=CHEBI%3A86465#:~:text=Potassium%20alum%20is%20commonly%20used,for%20minor%20bleeding%20from%20shaving>
- [11] From Thermo Fisher Scientific - Elemental and Phase Analysis et al., Accessed: Nov. 18, 2023. [Online]. Available: <https://www.azomining.com/Article.aspx?ArticleID=274>
- [12] Business Research Insight, “Alunite market size, share, growth, and industry analysis, by type (Natroalunite, potassium alunite), by application (Chemical & Material, agriculture industry, food), regional forecast to 2031.” Accessed: Nov. 10, 2023. [Online]. Available: <https://www.businessresearchinsights.com/market-reports/alunite-market-109255>
- [13] HealingCrystalsForYou.com, “Alunite meanings, properties and powers.” Accessed: Nov. 19, 2023. [Online]. Available: <https://www.healing-crystals-for-you.com/alunite.html>
- [14] M. Smith, “Bulahdelah alunite.” Accessed: Nov. 10, 2023. [Online]. Available: <https://www.nationalrockgarden.com.au/rock-collection/bulahdelah-alunite/>
- [15] W. Boericke, “De Materia Medica (1901).” Accessed: Nov. 10, 2023. [Online]. Available: <https://www.materiamedica.info/en/materia-medica/william-boericke/alumen>
- [16] M. Özacar, “Adsorption of phosphate from aqueous solution onto alunite,” *Chemosphere*, vol. 51, no. 4, pp. 321–327, 2003
- [17] Ph. D. Anne Marie Helmenstine, “Get the facts about alum and how it’s used in Everyday Life.” Accessed: Nov. 18, 2023. [Online]. Available: <https://www.thoughtco.com/what-is-alum-608508>
- [18] R. Jung, “Using alum to clarify muddy water on trips.” Accessed: Nov. 10, 2023. [Online]. Available: <https://backpackinglight.com/alum-water-clarification-backpacking/>
- [19] Dr. A. Pal, “Alum: Uses, benefits & side effects.” Accessed: Nov. 10, 2023. [Online]. Available: <https://pharmeasy.in/blog/ayurveda-uses-benefits-side-effects-of-alum/>
- [20] Z. Sherrell, “Alum for skin: Uses, benefits, safety, and more.” Accessed: Nov. 109, 2023. [Online]. Available: <https://www.medicalnewstoday.com/articles/alum-for-skin>
- [21] M. A. Ali, H. A. M. Ahmed, H. M. Ahmed, and M. Hefni, “Pyrophyllite: An Economic Mineral for Different Industrial Applications,” *Applied Sciences*, vol. 11, no. 23, p. 11357, 2021
- [22] M. Marafi and M. S. Rana, “Role of EDTA On Metal Removal From Refinery Waste Catalysts,” pp. 137–147, 2018

- [23] A. Talc, "Pyrophyllite Powder: Applications, uses, and its role as an exporter in Udaipur." Accessed: Nov. 20, 2023. [Online]. Available: <https://medium.com/@anandtalc0011/pyrophyllite-powder-applications-uses-and-its-role-as-an-exporter-in-udaipur-india-8c7981780324>
- [24] W. Zhang, "Application and progress on pyrophyllite in environmental pollution treatment[J]," *Journal of Environmental Engineering Technology*, vol. 8, no. 1, pp. 109–116, 2018.
- [25] H. Sayılkan, S. Erdemoğlu, Ş. Şener, F. Sayılkan, M. Akarsu, and M. Erdemoğlu, "Surface modification of pyrophyllite with amino silane coupling agent for the removal of 4-nitrophenol from aqueous solutions," *J Colloid Interface Sci*, vol. 275, no. 2, pp. 530–538, 2004
- [26] J. Kustura *et al.*, "Removal of heavy metals from landfill leach water using pyrophyllite as adsorbent," *Journal of Sustainable Technologies and Materials*, vol. 3, no. 4, pp. 7–15, 2023
- [27] J.-H. Kim, C.-G. Lee, J.-A. Park, J.-K. Kang, N.-C. Choi, and S.-B. Kim, "Use of pyrophyllite clay for fluoride removal from aqueous solution," *Desalination Water Treat*, vol. 51, no. 16–18, pp. 3408–3416, 2013
- [28] A. Sagar, "Spread Plate Technique- Principle, Procedure and Uses." Accessed: Nov. 18, 2023. [Online]. Available: <https://microbiologyinfo.com/spread-plate-technique-principle-procedure-and-uses/>