

ECOTOXICITY ASSESSMENT OF ALLIUM CEPA IN A WATER TREATMENT SYSTEM CONTAMINATED WITH BTEX

AVALIAÇÃO DE ECOTOXICIDADE EM ALLIUM CEPA EM SISTEMA DE TRATAMENTO DE ÁGUA CONTAMINADA COM BTEX

EVALUACIÓN DE LA ECOTOXICIDAD DE ALLIUM CEPA EN UN SISTEMA DE TRATAMIENTO DE AGUA CONTAMINADO CON BTEX



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ABSTRACT

This study investigated the removal of BTEX compounds from water using a compact device consisting of vacuum suction and an adsorption system with activated carbon and rice husk ash. These were followed by ecotoxicity tests that assessed the root length of *Allium cepa*, considering the raw sample at 100% (BTEX100) and the 50% (BTEX50) and 25% (BTEX25) dilutions. Samples were collected at the following points: A1 – suction well; A2 – vacuum system; A3 – adsorption filter. Three trials were conducted with a total duration of 240 minutes, with sampling at monitoring times of 0 minutes (T0), 120 minutes (T120), and 240 minutes (T240). The results showed removal efficiencies greater than 99% of the concentrations of the compounds studied using the compact device. This decrease is mainly attributed to the vacuum suction process. However, the ecotoxicity tests indicated the need for the adsorption step to reduce the toxicity of the treated water.

Keywords: Groundwater. BTEX. Toxicity. Adsorption. Rice Husk Ash. *Allium Cepa*.

RESUMO

Este trabalho estudou a remoção dos compostos BTEX em água, utilizando equipamento compacto composto por sucção à vácuo, aeração e sistema de adsorção com 50% de carvão ativado e 50% de cinza de casca de arroz. A concentração dos BTEX foi determinada por Cromatografia Gasosa. Os testes de ecotoxicidade avaliaram o comprimento da raiz da *Allium Cepa*, considerando a amostra bruta 100% (BTEX100) e as diluições de 50% (BTEX50) e de 25% (BTEX25). Executaram-se 03 ensaios com duração total de 240 minutos, com amostragens nos tempos de monitoramento de 0 minutos (T0), 120 minutos (T120) e 240 minutos (T240). Os resultados mostraram eficiências de remoção superiores a 99% das concentrações dos compostos BTEX estudados, o que está associado,

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principalmente, ao processo de sucção à vácuo. No entanto, os testes de ecotoxicidade indicaram a necessidade de incluir a etapa de adsorção ao tratamento, visando a redução da toxicidade da água tratada.

Palavras-chave: Água Subterrânea. BTEX. Toxicidade. Adsorção. Cinza da Casca de Arroz. Allium Cepa.

RESUMEN

Este estudio investigó la eliminación de compuestos BTEX del agua mediante un equipo compacto que consta de succión al vacío, aireación y un sistema de adsorción con 50 % de carbón activado y 50 % de ceniza de cáscara de arroz. La concentración de BTEX se determinó por cromatografía de gases. Se realizaron pruebas de ecotoxicidad para evaluar la longitud de la raíz de Allium cepa, considerando la muestra cruda al 100 % (BTEX100) y diluciones al 50 % (BTEX50) y al 25 % (BTEX25). Se llevaron a cabo tres pruebas con una duración total de 240 minutos, con muestreo a los 0 minutos (T0), 120 minutos (T120) y 240 minutos (T240). Los resultados mostraron eficiencias de eliminación superiores al 99 % de las concentraciones de los compuestos BTEX estudiados, lo cual se asocia principalmente al proceso de succión al vacío. Sin embargo, las pruebas de ecotoxicidad indicaron la necesidad de incluir una etapa de adsorción en el proceso de tratamiento, con el fin de reducir la toxicidad del agua tratada.

Palabras clave: Agua Subterrânea. BTEX. Toxicidad. Adsorción. Ceniza de Cáscara de Arroz. Allium Cepa.

1 INTRODUCTION

With the increasing number of use, transportation, storage, and disposal of petroleum products, soil and water pollution has become a critical environmental factor resulting from accidents and human activities involving these products (Li et al., 2020).

Gasoline and diesel oil are made up of hydrocarbons derived from petroleum such as the compounds benzene, toluene, ethylbenzene and the isomers (o, m, p) xylenes, also known as BTEX. The presence of BTEX in groundwater comes from fuel leaks in underground storage tanks, located at gas stations, leaks in pipes and spills on surfaces. The severity of these contaminations occurs due to the toxicity of these products that can cause serious environmental and public health problems (Yang et al., 2020; Khudur et al., 2019; Batista, Barros, Bárbara, 2021; Poddar et al., 2022; Flores-Chaparro et al., 2021).

BTEX have a lower density than water, so they form a contamination plume in groundwater and migrate easily with the movement of groundwater and can reach large areas of contamination (Yang et al., 2020). In this way, physical, chemical, and biological remediation techniques are applied for the recovery of contaminated sites (Li et al., 2020).

There are numerous technologies for the remediation of hydrocarbon-contaminated areas. Some treatment methods, such as bioremediation, chemical oxidation, Air Stripping and adsorption have already been employed and have been successful in removing these contaminants in water (Chiu et al., 2017). Caetano et al. (2016) employed a compact groundwater treatment system contaminated with BTEX and Total Petroleum Hydrocarbons (TPH) using vacuum suction system, aerators and adsorption filters. The results showed efficiencies of more than 90% in the removal of compounds. Cardoso, Lodi and Barros (2017) also report efficiency in groundwater treatment using Pump And Treat, Air Sparging, Advanced Oxidation Processes (AOP) and Bioremediation.

The Pump and Treat technique consists of pumping groundwater to the surface and applying other treatment methods, widely applied to volatile organic compounds (VOCs) or semi-volatiles in water. Another frequently used technique is Air Stripping by introducing an air current into contaminated water, promoting the release and transport of these contaminants into the air.

In the adsorption process, the contaminant is transferred from the liquid medium to the surface of the adsorbent material. Activated carbon (CA) is the most widely used due to its sorption properties, hydrophobicity, high surface area, and microporous structure (Ossai et al., 2020). However, due to their high cost of obtainment, difficulty of regeneration and the negative environmental impacts generated in their production, alternative, renewable and

low-cost materials such as industrial and agricultural waste are studied for water and effluent treatment (Foo; Hameed, 2009).

In this scenario, rice husk ash (CCA) is an alternative, an industrial waste usually originated in boilers by use for thermal energy generation. This material has a traditional final destination for dispersion in agricultural soil or industrial landfills, being a source of pollution due to the silica and carbon content in its composition (Camargo et al., 2018; Foo; Hameed, 2009). However, these characteristics allow the recovery of the waste for use as a co-product (Camargo et al., 2018; Foletto et al., 2005).

The use of CCA as an adsorbent in the treatment of water and effluents has been studied. For Foo and Hameed (2009), it has been shown to be a potential alternative adsorbent for wastewater treatment in the removal of organic and inorganic compounds. Kieling, Mendes and Caetano (2018) showed removals between 43% and 100% for effluents contaminated by Chromium VI using CCA as an adsorbent. Schmitt, Kieling, and Caetano (2020) applied CCA for the removal of emerging contaminants in aqueous solution. The research by Gomes et al. (2016), Caetano et al. (2016) and Caetano et al. (2018) showed removals greater than 90% with the use of CCA in the treatment of groundwater contaminated by BTEX and TPH.

In Brazil, the main legislation applicable to contaminated waters and soils is CONAMA Resolution No. 420/2009 (Brasil, 2009). The discharge of effluent into water resources must meet the requirements of CONAMA Resolution No. 430/2011 (Brasil, 2011). In addition to the traditional physical, chemical and biological parameters, the latter addresses the need for ecotoxicity tests to evaluate the toxic action of contaminants. (García-Medina et al., 2020).

For the verification of toxicity in water and effluents, the use of bioindicators stands out as a methodology. *Allium Cepa* (onion) is widely used in this application because it is easily cultivated and costs are low (Caetano et al., 2018).

Fiskesjö (1985) studied the root growth of *Allium cepa* to evaluate the toxicity in effluents. According to the author, the lower the concentrations of contaminants in effluents, the longer the length of the roots. This technique was also adopted in the research of Mazzeo et al. (2010), Caetano et al. (2018), and Kieling, Mendel, and Caetano (2018).

In this context, this research studied the use of a pilot-scale treatment system for the removal of BTEX present in groundwater contaminated by gasoline and diesel oil. The system used was composed of vacuum suction, aeration and adsorption filter with a composition of 50% CA and 50% CCA. The efficiency of the system was evaluated by BTEX removal and by the ecotoxicity test with *Allium Cepa*.

2 METHODOLOGY

2.1 PRESENTATION OF THE PILOT EXPERIMENT

The tests were carried out on a pilot scale (Caetano, 2014), in a remediation system installed at the University of Vale do Rio dos Sinos (UNISINOS). The treatment equipment developed is subdivided into three systems: vacuum treatment, aerators and adsorption filter. Figure 1 shows the equipment used.

Figure 1

Treatment equipment used in the trials



Legend: 1 – Reservoir for mixing water and contaminants; 2 - Suction well; 3 – Booster pump; 4 – Vacuum suction system; 5 – Aerators; 6 – Adsorption Filter; 7 – Treated water reservoir.
Source: Authors (2026)

The description of the equipment components is as follows:

- 1 - 5,000L reservoir for storage of water contaminated with diesel and regular gasoline (R1): rainwater and a mixture of 2.5L of regular gasoline and 2.5L of regular diesel were used to make the contaminated water, simulating groundwater contaminated by leaks at gas stations. The mixture was carried out for 30 minutes through a submerged pump at room temperature.
- 2 – Suction Well (Collection Point A1): a simulation of the soil profile and a suction well installed were carried out. The soil profile was executed inside a 500 mm PVC pipe. It consisted of layers of synthetic soil with horizons A (thickness of 0.2 m), B (thickness of 1.7 m) and C (thickness of 0.1 m). In the middle of the soil profile, a suction well composed of a 50 mm diameter pipe was installed.
- 3, 4 – Suction system (Collection point A2): the pumping process was carried out by suction of the water using a venturi injector. The treatment occurred partly by volatilization of organic compounds by the negative pressure provided (-700 mm Hg) and partly by *Air Stripping*. The gas outlet occurred through the drain at the top of the

equipment and treated by powdered activated carbon adsorption filters. The water flow at this point was about 0.027 L/s.

- 5 – Aerators: diffuse air aeration process (aspiration aerators). The propeller immersed in the liquid created a subpressure by sucking atmospheric air from a groove located at the top. The air diffused into the liquid medium in small bubbles, oxygenating and mixing the liquid mass. The process of removing the VOCs, as well as the suction stage, was by *Air Stripping*, however, with only oxygen ingress. The exit of the gases occurred through the drain at the top of the equipment. The water flow rate in aerator 1 was 0.026 L/s and in aerator 2 was 0.40 L/s.
- 6 – Adsorption Filter (Collection Point A3): water flowed through the mixed column (adsorbents: 50% CA and 50% CCA). The contaminants were adsorbed by the column, treating the water progressively until the filter came out. An adsorbent mass of 33.1 kg of CCA and 29.6 kg of AC was used. Corresponding to an adsorbent volume of 0.034 m³. The water inlet flow was equal to 0.04 L/s and the percolation speed was 0.08 cm/s.
- 7 – 5,000L reservoir for treated water storage (R2): 5,000 liter reserve for treated water.

2.2 CHARACTERIZATION OF ADSORBENT MATERIALS

The characteristics of AC and OKC are presented in Table 1 below.

Table 1

Characteristics of activated carbon (AC) and rice husk ash (CCA)

Parameter	CA Granular	CA Fino	CCA	Characterization methodology
pH	7,10	2,85	8,0	Ng Chilton et al. (2002)
Conductivity (µS/cm)	866,5	1470	81,70	Ng Chilton et al. (2002)
Specific mass (g/cm ³)	1,5135	1,7043	19	ABNT NBR-6508/1984
Grain size (mm)	4,05 - 0,425	0,297 – 0,044	1,70 - 0,053	ASTM D850, 2002
Percentage of loss to fire (%)	86,23	67,49	7,20	ABIFA, 2003

Source: Authors (2026)

The CA used comes from the chemical activation of burnt coconut shells from the supplier in the State of Paraná, Brazil. CCA, on the other hand, is the result of combustion in a boiler of a food company in Rio Grande do Sul, Brazil, which uses rice husk as fuel. The rice husk is automatically fed in a continuous system, with a burning condition of 900°C for 9 minutes. CCA was used in its natural form, without chemical or thermal treatment and was

segregated to improve the uniformity of the material, removing undesirable particles, such as unburned rice husks. Segregation was performed by a sieve shaker (1.2 mm mesh) for 5 minutes.

The chemical analysis (Energy dispersive X-ray Fluorescence Spectrometer, brand EDX 720 HS - Shimadzu) indicates that the major component found in CCA is silicon (85%), showing traces of other elements such as iron, manganese, calcium, potassium and phosphorus. For CA, the inorganic fraction showed silicon, sulfur, iron, copper, calcium, potassium and phosphorus. A higher concentration of potassium was observed, which associated with the alkaline pH of the material, indicates a possible activation with potassium hydroxide.

In the XRD tests (Siemens D5000 diffractometer), it was observed that the gross CCA and the segregated CCA presented the amorphism halo, which corresponds to the deviation from the baseline between the angles of 15° and 30°, indicating the amorphity of the material. According to the peaks presented, the silica of this ash may be present in the form of cristobalite. The CA diffractogram, on the other hand, indicated that the material is amorphous.

An analysis of the microstructure of the CCA (SEM Equipment, Shimadzu SSX-550) demonstrated that the burning is not uniform, resulting in particles with different particle sizes due to temperature and residence time during the combustion process. It was observed that CCA particles are formed by two parts: an external one, formed by a denser structure; the other internal, more porous that indicates the potential of its use as an adsorbent.

The kinetic studies demonstrated that CCA and CA have high and similar adsorption capacities at equilibrium time of 120 minutes. In general, the removal took place in the following order: ethylbenzene > xylene > toluene > benzene. The pseudo-second-order kinetic model (Table 2) showed the best correlation for all trials.

Table 2

Constants for Pseudo-second order for monocompounds

Compound	C0 (mg/L)	CCA				CA			
		QE (mg/g)	K2 (g.min/mg)	H2 (mg/g.min)	R2	QE (mg/g)	K2 (g.min/mg)	H2 (mg/g.min)	R2
Benzene	1	0,0971	8,5804	0,0809	0,9999	0,0984	2,0758	0,0201	0,9989
	5	0,4914	1,0647	0,2571	0,9998	0,5106	0,2880	0,0751	0,9981
	10	0,9739	0,218	0,2068	0,9988	1,047	0,0418	0,0459	0,9804
	20	1,7658	0,1434	0,4473	0,9992	2,1083	0,0156	0,0693	0,9665
Toluene	1	0,0997	15,5431	0,1545	0,9999	0,1005	2,8415	0,0287	0,9994

	5	0,4919	0,9497	0,2298	0,9998	0,4989	0,2523	0,0628	0,9969
	10	0,9706	0,6154	0,5798	0,9999	1,0018	0,1157	0,1162	0,9967
	20	1,8814	0,2737	0,9688	0,9998	2,0759	0,0271	0,1168	0,987
Ethylbenzene	1	0,10005	48,8011	0,4885	0,9999	0,1015	0,1941	0,002	0,9987
	5	0,4967	18,9404	4,6728	0,9999	0,5031	0,4302	0,1089	0,999
	10	0,9964	1,8823	1,8688	0,9999	0,9989	0,2894	0,2888	0,9994
	20	1,9908	0,4864	1,9278	0,9999	2,012	0,1724	0,6979	0,9996
Xylene	1	0,10009	58,1652	0,5827	0,9999	0,1007	1,4989	0,0152	0,9979
	5	0,501	2,8581	0,7174	0,9999	0,5049	0,5962	0,152	0,9996
	10	0,9906	0,7963	0,7814	0,9999	1,0039	0,3043	0,3067	0,9996
	20	1,95	0,1811	0,6889	0,9996	1,9896	0,0776	0,3073	0,9975

Legend: k_2 is the constant of the adsorption velocity (g.min/mg); q_e is the amount adsorbed at equilibrium (mg/g); h is the initial adsorption rate (mg/g.min); R_2 is the correlation coefficient.

Source: Authors (2026)

The experimental isotherms obtained for the monocompounds characterize the adsorption on porous surfaces with monolayer formation. The adjustments to the theoretical models were not unanimous, and in some situations there was an adequate correlation for Langmuir and Freundlich (Table 3).

Table 3

Model parameters for monocompounds

Langmuir model								
Compounds	CCA				CA			
	Qo (mg/g)	KL (L/mg)	RL	R2	Qo (mg/g)	KL (L/mg)	RL	R2
Benzene	13,33	0,1643	0,8762	0,9505	13,51	0,2054	0,8504	0,7675
Toluene	0,7868	14,233	0,2863	0,9387	0,7636	11,299	0,2820	0,9291
Ethylbenzene	0,8795	63,16	0,3134	0,9604	15,97	0,2208	0,9615	0,988
Xylene	1,64	14,89	0,4927	0,9137	3,22	0,853	0,7822	0,9704
Freundlich Model								
Compounds	CCA			CA				
	n	KF (mg/g)(L/mg) ^{1/n}	R2	n	KF (mg/g)(L/mg) ^{1/n}	R2		
Benzene	1,6482	0,9669	0,9204	1,9094	0,9519	0,8458		
Toluene	1,6382	25,351	0,9591	1,569	1,2525	0,924		
Ethylbenzene	1,6866	3,619	0,9942	0,8309	6,1108	0,9616		
Xylene	2,47	1,8736	0,9589	1,2993	1,9023	0,9174		

Legend: Q_0 is the maximum adsorption capacity (mg/g); K_L are the adsorbent-adsorbate interaction forces (L/mg); R_L is an equilibrium parameter; K_F is the distribution of the active adsorption sites (mg/g) (L/mg)^{1/n}; n is the adsorption capacity of the adsorbent.

Source: Authors (2026)

2.3 TESTS FOR EVALUATION OF VACUUM AND ADSORPTION TREATMENT

Before the start of the first sampling, a 1h30min recirculation was carried out in all the equipment to standardize the contaminated water. The supply of the system was continuous during all tests. There were three rehearsals lasting 240 minutes each. The contaminated

water was transferred from the 5,000L reservoir (1) to the suction well (2), as shown in Figure 1. Therefore, the initial BTEX concentration for the three assays and at the three monitored times were different from each other.

The collections were carried out at points A1 - suction well; A2 – vacuum system; A3 – adsorption filter. Sampling was carried out at monitoring times of 0 minutes (T0), 120 minutes (T120) and 240 minutes (T240). For this purpose, 1L amber flasks were used, which were refrigerated between 0°C and 6°C.

For the quantification of contaminants, the samples were transferred to vials with 5mL of saturated NaCl solution, to increase the ionic strength of the solution, enriching the gas phase by reducing the solubility of the hydrocarbons by altering the equilibrium between the phases (Nogueira, 2006).

The concentration of BTEX was determined using a Gas Chromatograph (GC) with Flame Ionization Detector (FID), DANI, with Master DHS Dynamic Headspace of the same brand. The column used was from the brand DANI DN-WAX with the following characteristics: 30 m in length, 0.25 mm in internal diameter, 0.25 µm in film thickness, 40°C lower temperature limit and 250 °C upper temperature limit.

The analysis method was adapted from the methodology proposed by the U.S. Environmental Protection Agency (EPA), method No. 8260C. The adaptation was necessary due to the conditions of the column used, promoting a better quality of the chromatogram.

The samples were automatically injected through a Headspace sampler with an oven temperature of 40°C, with no incubation time and no shaking. The operating conditions used in the CG were: Carrier gas – Nitrogen; flow rate – 0.7 mL/min for 6 minutes, 2mL/min to 1mL/min flow; injector temperature - 200°C; FID detector temperature - 280°C; Split ratio - 1:50; initial temperature of 40°C, isotherm of 1 min, 2°C/min up to 70 °C and 50°C/min up to 220°, for an injected volume of sample of 100 µL. The identification and quantification of substances (BTEX), obtained by the DHS CG-FID, as well as the management of the DHS and CG-FID, were performed with the software for the Windows Clarity™ computer system version 4.0.04.987.

2.4 ECECOTOXICITY TESTS

The ecotoxicity tests were carried out based on the method proposed by Fiskesjö (1985), whose macroscopic evaluative parameter and responsible for the conclusion regarding the toxicity of the effluent corresponds to the length of the root of *Allium Cepa* (common onion) at the end of the tests.

The units of *Allium Cepa* used in the trial were selected by looking for bulbs of small diameters (about 20 to 30mm), dry and with absence of leaves or roots. The outer layers and roots were removed, keeping intact the primordial ring, from which new roots develop. Test tubes were used for the test (ϕ : 2.50cm and h: 15.00cm).

Collection points A1, A2 and A3 were evaluated at the monitoring times T0, T120 and T240. Samples were analyzed with 25% (BTEX25), 50% (BTEX50) and 100% (BTEX100) BTEX solution, and dilutions were performed with drinking water. Five replicates were monitored for each dilution and assay time. Drinking water was used as a negative control sample.

The bulbs of *Allium Cepa* were arranged in contact with the dilutions and taken to the germination chamber at controlled room temperature (+20°C), protected from sunlight, with a photoperiod of 16 hours light and 8 hours dark, for a period of 96 hours.

The volume lost by evaporation or absorption by the bioindicator was replenished once a day with the respective dilutions, stored in a refrigerator at a temperature of +4°C. At the end of the period, five measurements were made referring to the five largest roots in length of each *Allium Cepa* using a common ruler.

Finally, the Relative Control Index (ICR), which relates the length of the roots of the solutions to the control sample, was calculated as presented in Equation 1 and the Inhibition Index (Ii), which represents the resistance to root growth, was calculated according to Equation 2. The normality test was applied to verify whether the data were normally distributed, and for analysis of variance, the ANOVA method and TUKEY analysis were used, considering a confidence level of 95% ($p \leq 0.05$).

$$ICR = \frac{Lm}{Lc} \quad (1)$$

$$Ii = 100 - \left(\frac{Lm}{Lc} \right) \quad (2)$$

Where:

ICR: Relative growth rate (%);

Ii: Inhibition Index (%)

Lm: Average length of the roots of the sample (cm);

Lc: Average length of control roots (drinking water) (cm).

3 RESULTS AND DISCUSSIONS

3.1 INITIAL CONCENTRATION OF BTEX (A1)

The initial concentration of BTEX at the entrance of the system through the suction well, called Sample A1, was evaluated. Table 4 shows the monitoring at times 0, 120 and 240 minutes, considering the means obtained in the three tests performed.

Table 4

Mean initial BTEX concentration (Sample A1) for the three assays performed

Parameter (mg/L)	T0	T120	T240	Average	Standard deviation	Research Level (CONAMA 420/2009)
Benzene	0,422	0,950	1,247	0,873	0,418	0,005
Toluene	1,572	3,894	4,695	3,387	1,622	0,700
Ethylbenzene	0,175	0,381	0,470	0,342	0,151	0,300
P-xylene	1,569	2,593	3,149	2,437	0,801	-
M-Xylene	2,388	4,210	4,993	3,864	1,337	-
O-xylene	3,550	6,197	7,232	5,660	1,899	-
Total Xylene	7,507	12,999	15,373	11,960	4,035	0,500

Source: Authors (2026)

The concentrations of BTEX used are based on studies that monitored the presence of these compounds in contaminated areas. According to the EPA (1997), in the United States, BTEX concentrations ranging from 6 to 24 mg/L are reported. (2000) showed concentrations between 0.024 and 198 mg/L, with monitoring in 49 contaminated areas.

Afferden et al. (2011), in Germany, found initial concentrations of benzene in the order of 13.046 – 18.625 mg/L, toluene between 0.0067 – 0.008 mg/L, ethylbenzene between 0.031 – 0.050 mg/L and xylene between 0.0637 – 0.0825 mg/L. In Austria, Wirthensohn et al. (2009) evaluated contaminated groundwater with BTEX concentrations between 0.295 – 0.806 mg/L. And in Taiwan, Chen et al. (2010) observed BTEX concentrations between 0.0039 – 2.838 mg/L. In Brazil, studies such as the one by Gomes et al. (2014) and Caetano et al. (2016) also cite significant contamination of groundwater by hydrocarbons.

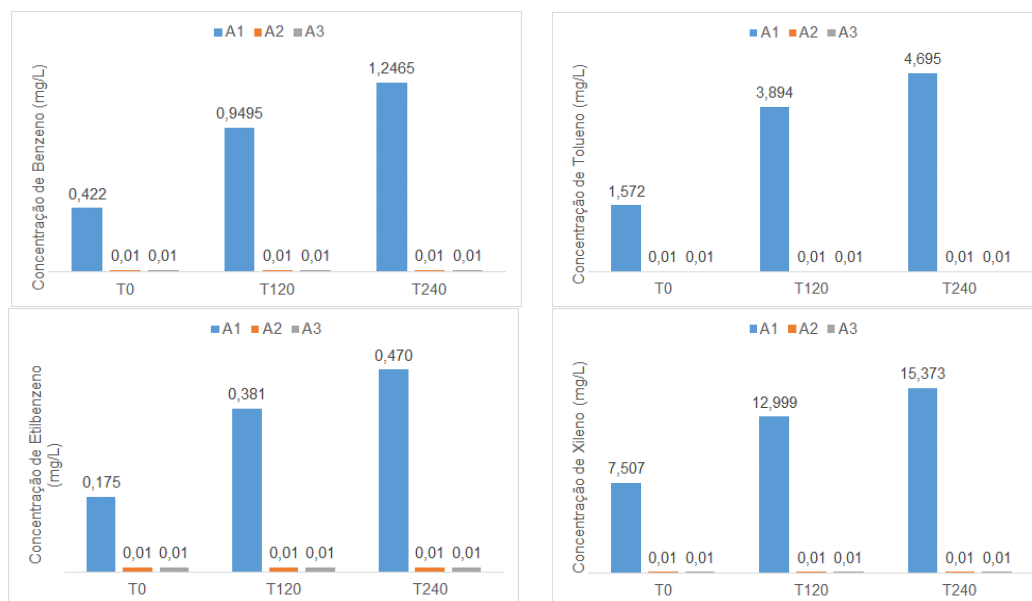
As shown in Table 4, the BTEX concentrations evaluated in the assays are higher than the levels of investigation required by national legislation, in this case, CONAMA Resolution No. 420/2009 (Brasil, 2009). These are values that represent the reality in contaminated areas, meeting the research proposal regarding the evaluation of an efficient treatment system for the removal of volatile hydrocarbons.

3.2 VACUUM SUCTION TREATMENT (A2) AND ADSORPTION (A3)

The mean results of the BTEX concentrations, considering the 3 assays performed, are shown in Figure 2. As the treatment was continuously supplied by contaminated water stored in the 5,000L Reservoir (Figure 1), the initial concentration of raw water was different for each monitored time.

Figure 2

Results of vacuum and adsorption treatment (average of the 03 assays performed) in BTEX



Legend: A1- suction well; A2 – vacuum system; A3 – adsorption filter.

Source: Authors (2026)

Figure 2 demonstrates the efficiency of vacuum suction treatment (A2) with a decrease in BTEX concentrations close to 100%. The results found are more effective compared to those presented by Caetano et al. (2016), in the order of 67.4% for Pilot Scale and 96.66% for Real Scale.

The use of *Air Stripping* or *Air Sparging* to reduce the concentration of VOCs are reported as efficient removal processes. Other studies that have used these technologies have shown levels of reduction in BTEX concentration in the order of 94.25% (EPA, 1997); 99.8%-99.9% (Khan; Husain; Hejazi, 2004), 30%-100% (Juneau Jr; Moyer; O'Connell, 2007), 95%–100% (Wirthensohna et al., 2009), 97%–100% (Afferden et al., 2011), and 100% (Franco; Chairez; Poznyaka; Poznyaka, 2012).

Regarding the treatment by adsorption, the removal of the compounds obtained is consistent with other similar studies, such as the research of Ayotamuno et al. (2006), Wirthensohn et al. (2009), Juneau et al. (2007), Caetano (2014), Gomes et al. (2014), Kieling (2016), and Caetano et al. (2016).

After the treatment performed, the reduction of the concentrations of toluene, ethylbenzene and xylene are sufficient to meet the Level of Investigation provided for by the National Legislation, CONAMA Resolution No. 420/2009 (Brasil, 2009). Regarding benzene, it is not possible to establish a precise conclusion due to the detection limit of the method being 0.01 mg/L and CONAMA 420/2009 reporting the investigation level for this parameter of 0.005 mg/L.

3.3 ECECOTOXICITY TESTS

Root growth was not uniform and, as a result, several units of *Allium Cepa* were used to obtain a more accurate result, as recommended by the methodology of Fiskesjö (1985). For the statistical analysis, all data from Trials 1, 2 and 3 were applied, since they were similar.

The results of root growth are shown in Table 5.

Table 5

Values of the root lengths of the Control (Drinking Water) and BTEX Samples

BTEX	Essay	Time (min.)	Root Growth (cm)					
			Average	A1 Standard Deviation	Average	A2 Standard Deviation	Average	A3 Standard Deviation
Control	1	-	5,3	1,3	5,3	1,3	5,3	1,3
	2	-	2,8	1,1	2,8	1,1	2,8	1,1
	3	-	3,7	1,1	3,7	1,1	3,7	1,1
BTEX25 %	1	0	2,9	1,3	4,3	1,6	2,9	1,4
		120	1,8	1,3	4,2	1,6	1,9	1,4
		240	2,0	1,2	4,0	1,4	2,1	1,6
		Average	2,2	1,3	4,2	1,5	2,4	1,4
	2	0	1,6	1,5	2,4	0,6	2,2	1,1
		120	1,2	0,5	1,2	1,0	3,0	0,5
		240	1,9	1,1	1,1	1,3	2,4	0,8
	Average	1,5	1,1	1,6	1,1	2,6	0,9	
	3	0	1,0	1,4	4,2	1,3	3,5	1,3
		120	1,7	0,8	3,8	0,6	3,0	1,0
		240	1,6	1,0	3,7	1,2	3,5	1,0
		Average	1,5	1,1	3,9	1,2	3,5	1,1
BTEX50 %	1	0	2,0	0,9	4,0	1,4	5,0	1,2
		120	1,4	0,7	2,9	1,1	4,3	1,2
		240	1,4	0,9	3,2	0,9	4,0	1,0
		Average	1,6	0,9	3,3	1,1	4,3	1,2
	2	0	0,8	0,5	2,7	0,4	2,5	0,7
		120	0,4	0,2	0,7	0,7	1,6	1,2
		240	0,0	0,2	2,5	1,0	2,7	0,5
	Average	0,3	0,4	2,2	1,1	2,5	1,0	
	3	0	1,0	1,1	4,1	1,6	4,3	0,4
		120	0,4	0,3	3,4	0,6	3,5	0,6
		240	0,7	0,3	3,1	0,8	3,6	0,3
		Average	0,7	0,7	3,5	1,1	3,9	0,6
BTEX10 0%	1	0	0,5	1,0	3,9	1,5	4,1	0,9
		120	0,1	0,9	3,3	1,4	4,0	0,7

	240	1,5	0,9	3,3	1,4	3,6	0,7
	Average	0,8	0,9	3,4	1,4	3,8	0,8
2	0	0,3	0,2	2,5	0,6	1,9	0,8
	120	0,2	0,2	2,5	0,9	1,8	0,7
	240	0,0	0,2	2,3	0,6	2,1	0,6
	Average	0,2	0,2	2,5	0,7	2,0	0,7
3	0	0,3	0,3	4,3	0,8	4,2	1,3
	120	0,0	0,2	3,0	0,7	4,8	0,7
	240	0,4	0,3	2,5	0,9	4,0	0,7
	Average	0,3	0,3	3,0	1,1	4,2	1,0

Source: Authors (2026)

The ANOVA and Tuckey tests showed significant differences ($p = 0.000$) between the root growth of the "Control" samples in relation to the BTEX25, BTEX50 and BTEX100 samples.

In the BTEX25 dilution, for the three assays performed and considering the T120 and T240 treatment times, the tests showed that there are no significant differences between the root growth for the A1 x A2 samples (T120 - $p = 0.275$; T240 - $p = 0.365$), A1 x A3 (T120 - $p = 0.210$; T240 - $p = 0.410$) and A2 x A3 (T120 - $p = 0.246$; T240 - $p = 0.294$). This is the same result for T0 comparing treatments A1 x A2 (T0 - $p = 0.882$) and A2 x A3 (T0 - $p = 0.620$). However, the statistical tests showed a significant difference comparing the T0 - A1 x A3 samples ($p = 0.012$) indicating the need for adsorption treatment to reduce ecotoxicity by BTEX, considering the 25% dilution. The efficiency of adsorption treatment using CCA and CA in reducing ecotoxicity (test with *Allium Cepa*) was also obtained by Caetano et al. (2018).

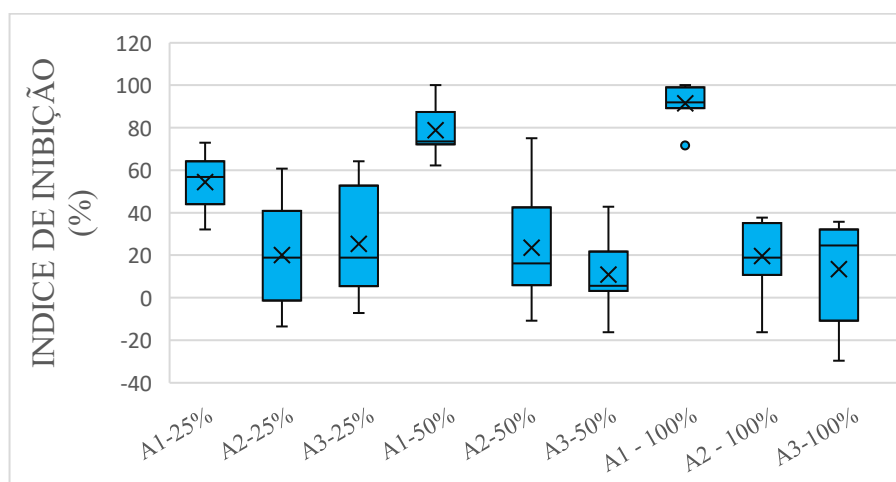
This statement is confirmed by analyzing the BTEX50 dilution. The ANOVA and Tuckey tests showed significant differences for samples A1 x A2 (T120 - $p = 0.000$); A1 x A3 (T120 - $p = 0.011$; T240 - $p = 0.000$); A2 x A3 (T0 - $p = 0.000$; T120 - $p = 0.000$).

Finally, for BTEX100, significant differences were obtained for T120 by comparing samples A1 x A2 ($p = 0.004$) and A2 x A3 ($p = 0.017$). Thus, with a higher concentration of volatiles, the use of vacuum treatment has a significant difference in treatment efficiency, a fact addressed by Caetano et al. (2016).

Figure 3 shows the results of the Mean Inhibition Index of the three toxicity assays, considering the BTEX concentration (25%, 50% and 100%) of the three samples studied (A1, A2 and A3).

Figure 3

Results of the inhibition index (%) in *Allium cepa* from vacuum and adsorption treatment



Source: Authors (2026)

The inhibition index (Ii) obtained indicates the resistance of the growth process that occurs in the roots of *Allium Cepa*. In this sense, the higher the value of Ii, the smaller the size of the roots. The results indicate the highest values of Ii for samples A1 (without treatment), with a decrease in Ii, as the dilution of the BTEX concentration occurs, with sample A1- 100% being the one with the highest inhibition index (91.51%). For the A2 samples (vacuum treatment), the means found for the values of Ii presented approximate values, being 20.01% for 25% of BTEX, 23.58% for 50% of BTEX and 19.59% for 100% of BTEX, indicating that the treatment applied contributes to the reduction of the inhibition index, considering the decrease in relation to the samples of the A1 set. In relation to the A3 samples (adsorption), the mean values for the inhibition index were 25.35% for 25% BTEX, 10.90% for 50% BTEX and 13.43% for 100% BTEX, indicating that the adsorption process can contribute to a greater growth of the roots, considering the decrease observed between the A2 and A3 samples in the concentration of 50% and 100% of BTEX.

In general, the assays contributed to evaluate the toxicity of BTEX in the germination and growth of *Allium Cepa* roots, since quantitative differences were observed in the number of roots and in their length, considering the concentrations of BTEX evaluated. In the work of Mazzeo et al. (2010) it was observed that with the biodegradation of BTEX present in water, there is a reduction in the genotoxic damage of *Allium cepa cells*. These results indicate that *Allium Cepa* is a good indicator of toxicity of water contaminated by BTEX, as well as an efficient means of evaluating the removal of these compounds in the system studied.

4 CONCLUSION

The compact equipment composed of vacuum suction, aeration and adsorption (AC and CCA) proved to be efficient, obtaining high performance for the removal of organic contaminants present in water. The rate of decrease in BTEX concentrations was around 99% in all assays. It was found that the treatment stage "Vacuum Suction" was the main responsible for such efficiency, being essential to meet the level of investigation provided for by the national legislation (CONAMA Resolution No. 420/2009).

Ecotoxicity tests, using *Allium Cepa* as a test organism, confirmed the reduction of the toxicity of contaminated water after suction (A2) and adsorption (A3). In addition, the statistical analyses (ANOVA and Tuckey) indicated the need for polishing the treatment after suction, using the adsorption filter composed of 50%-CCA and 50%-CA. Although most of the BTEX concentration was removed in the "Vacuum Suction" treatment, for the BTEX25 and BTEX50 dilutions, significant differences in toxicity were found comparing the A2 and A3 samples. Reinforcing the need for the adsorption process to reduce the toxicity of contaminated water.

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