INSTITUTO POLITÉCNICO DE BRAGANÇA
Escola Superior de Tecnologia e Gestão

Monitoring of emerging micropollutants in water matrices and its removal by adsorption processes using biomass-based materials

MOHAMED BEN BELGACEM

Dissertation presented to Escola Superior de Tecnologia e Gestão of Instituto Politécnico de Bragança for the Master's Degree in Chemical Engineering

Supervised by

Professor Ana Maria Queiroz

Professor António Ribeiro

Professor Paulo Brito

Bragança

July, 2024

Acknowledgements

First and foremost, praises and thanks to the God, the Almighty, for His showers of blessings throughout my research work to complete it successfully.

I want to thank IPB for giving me this opportunity to be part of this master's degree. Also, I would like to express my deep and sincere gratitude to my research supervisors, Ana Queiroz, António Ribeiro and Paulo Brito, for their consistent support and guidance during the running of this research. their dynamism, vision, sincerity, and motivation have deeply taught me. It was a great privilege and honor to work and study under their guidance. I am also grateful to Dr. Paula Plasencia for helping me during some of the experiments.

I am extremely grateful to my parents for their love, prayers, caring and sacrifices for educating and preparing me for my future. I also express my thanks to my sisters, and brothers, for their support and motivation.

Abstract

Sertraline is a pharmaceutical drug used for the relief of depressive severe situations. Since sertraline has been widely prescribed for medical purposes in Portugal for the past ten years and may thus be found in various water media, it was employed in this work as a prototype antidepressant molecule for removal investigations using biobased materials, such as olive stones.

The present work aims to study the removal of sertraline through adsorption using activated charcoal from the olive pit. Therefore, this work is based on the preparation of the adsorbent from the olive stone, namely activated carbonized then make the physicochemical characterization and study the process of removal of sertraline by the experimental measuring of main operational conditions of pH, mass of adsorbent, temperature and kinetics of adsorption. The removal studies showed that the optimal pH for the adsorption of sertraline was around neutrality, The effect of the olive stone activated carbon dosage on sertraline removal was studied by varying the amount of the adsorbent from 10 mg to 55 mg presenting a maximum adsorption equal to 97% with 55mg in 48h. The adsorption process was chemisorption in nature since the kinetics behavior is better described by the pseudo-second order reaction model.

Resumo

A sertralina é um fármaco utilizado para o alívio de situações depressivas graves. Uma vez que a sertralina tem sido amplamente prescrita para fins médicos em Portugal na última década e pode, portanto, ser encontrada em vários ambientes aquáticos, foi utilizada neste trabalho como molécula protótipo de antidepressivo para a investigação sobre a eliminação utilizando materiais de base biológica, tais como caroços de azeitona.

O presente trabalho tem como objetivo estudar a remoção da sertralina por adsorção utilizando carvão ativado do caroço da azeitona. Assim, este trabalho tem como base a preparação do adsorvente a partir do caroço da azeitona, nomeadamente o carvão ativado carbonizado, de seguida fazer a caraterização físico-química e estudar o processo de remoção da sertralina através da medição experimental das principais condições operacionais de pH, massa de adsorvente, temperatura e cinética de adsorção. O efeito da dosagem de carvão ativado de caroço de azeitona na remoção da sertralina foi estudado variando a quantidade de adsorvente de 10 mg a 55 mg, apresentando uma adsorção máxima igual a 97% com 55 mg em 48h. O processo de adsorção foi de natureza química, uma vez que o comportamento cinético é melhor descrito pelo modelo de reação de pseudo-segunda ordem.

Résumé

La sertraline est un médicament pharmaceutique utilisé pour soulager les situations dépressives graves. La sertraline étant largement prescrite à des fins médicales au Portugal depuis une dizaine d'années et pouvant donc se retrouver dans divers milieux aquatiques, elle a été utilisée dans ce travail comme prototype de molécule antidépressive pour les recherches sur l'élimination à l'aide de matériaux biosourcés, tels que les noyaux d'olive.

Le présent travail vise à étudier l'élimination de la sertraline par adsorption à l'aide de charbon actif provenant du noyau d'olive. Ainsi, ce travail est basé sur la préparation de l'adsorbant à partir du noyau d'olive, à savoir le charbon actif carbonisé puis faire la caractérisation physicochimique et étudier le processus d'élimination de la sertraline par la mesure expérimentale des principales conditions opérationnelles de pH, de masse d'adsorbant, de température et de cinétique d'adsorption. L'effet du dosage du charbon actif à base de noyaux d'olive sur l'élimination de la sertraline a été étudié en faisant varier la quantité d'adsorbant de 10 mg à 55 mg, ce qui a permis d'obtenir une adsorption maximale de 97% avec 55 mg en 48h. Le processus d'adsorption était de nature chimisorption puisque le comportement cinétique est mieux décrit par le modèle de réaction du pseudo-second ordre.

Table of Contents

List of Figures

List of Tables

List of abbreviations

AC	Activated carbon
ACC	Activated carbonized carbon
API	Active pharmaceutical ingredient
EP	Emerging pollutants
FTIR	Fourier Transform Infrared Spectroscopy
NSAID	Non-steroidal anti-inflammatory drugs
OSAC	Olive stone activated carbon
PCP	Personal care products
PPCP	Pharmaceuticals and personal care products
PHpzc	Point of zero charge
SPT	Sewage treatment plants
SSRIS	Selective serotonin reuptake inhibitor
UV-Vis	Ultraviolet-visible
WWTP	Wastewater treatment plants

Nomenclature

A	Absorbance (UA)
C	Molar concentration of the sample (mg/L)
C_e	Sertraline concentration in the aqueous solution (mg/L)
ε	Molar absorptivity coefficient of the sample (L/(mol.cm))
I	Intensity of transmitted light
I_0	Incident light intensity in the detection cell
l	Length of the optical path in the detection window (cm)
m	Mass (mg)
n_F	The heterogeneity factor of Freundlich Equation
r	Correlation coefficient (linear regression)
q_e	Amount of adsorbed sertraline on the adsorbent (mg/g)
S_{ext}	External surface area (m^2/g)
S_{BET}	BET method surface area (m^2/g)
S_{mic}	Micropores surface área (m^2/g)
T	Temperature (C°)
t	Time (min)
V	Volume (ml)
V_{mic}	Micropores volume (mm^3/g)
V_{Total}	Total pore volume (mm^3/g)
W_{mic}	Average pore width (nm)

1. Background and objectives

1.1. Background

Pharmaceutical substances are spread out over several environmental matrices and enter the environment from a variety of anthropogenic sources. Despite the fact that significant progress has been made in the discovery and analysis of trace contaminants in recent decades, there are still a wide range of undetected pollutants of emerging environmental concern that need to be linked and quantified in various environmental factors and biological tissues.

Even at low concentrations, these pollutants may be dispersed and persistent in the air, water, soil, sediments, and ecological receptors (Paíga *et al.*, 2019). There is still a lack of accurate information on their fate, how they interact with the environment, and the risks they pose to both human and ecological health. Additionally, because there are frequently insufficient data to assess the harm posed by some developing micropollutants, the ecotoxicological impact of these pollutants is still mostly unclear. Pharmaceuticals are typically found in ambient air at incredibly low amounts, on the order of parts per million or even less (lolic et al.,2015). Similar low concentrations necessitate careful extraction process optimization. On the other hand, it is advantageous to create procedures that are quicker, cheaper, greener, and better for the environment than those now used that rely on conventional techniques. Despite the fact that the prevalence of pharmaceuticals in the environment is well-known and quantified, this issue is garnering scientific and public attention due to the significant environmental harm they inflict (Paíga *et al.*, 2019).

Personal care products, insecticides, hormones, as well as pharmaceuticals in general, are among the main classes of chemical compounds that can be detected in environmental compartments such water, sediment, and biota. Domestic sewage releases and industrial wastewater discharges are the main pathways for these chemicals to disperse. Pharmaceuticals are a diverse group of compounds with different modes of action (antibiotics, antidepressants, psychoactive, anti-inflammatory, etc.), raising the possibility of risk to biological species from exposure to active metabolites or unmodified drugs meant for human and/or animal use. Sertraline has been heavily prescribed for medical purposes in Portugal for the past ten years and can thus be found in various water media. Therefore, it was used in this work as a prototype

antidepressant molecule for removal investigations using biobased materials, such as olive stones.

1.2. Objectives of the work

In this work several experimental results will be presented for the removal of sertraline using activated carbon materials prepared from olive stones, namely activated carbon and carbonized carbon.

Therefore, the main objectives of this work are:

- Preparation of the adsorbent using activation and carbonization methods.
- Study the adsorption removal process by the experimental measuring of the equilibrium adsorption isotherms.

2. Water Pollution

2.1. Classification of water pollution

Usually, water pollution is observed in a chemical or biological nature. Additionally, there are few areas in the world that are not affected by some type of pollution in aqueous matrices (Bard and Cann, 2011; Boelee *et al*., 2019). The interaction and consumption of contaminated water can have a number of negative health impacts on living beings, and it is strongly linked to diseases that affect the entire global population (Amin *et al.*, 2014). The existence and spread of both toxic and non-toxic organic and inorganic compounds contribute to the characterization of chemical contamination of water (Cruz *et al.*, 2015)., we can justify the identification of chemicals in animals and living things through biological amplification. For instance, mercury used for gold mining in rivers and lakes makes its way up the food chain until it reaches the final consumer (Braga *et al.*, 2005).

2.2. Classification of pollutants

Due to the rise in the number of harmful pollutants in water, chemical pollution causes changes to the water's natural chemical properties, being the most prevalent, persistent and far-reaching. It can be organic (phenols, naphthenic acids, pesticides, etc.) and inorganic (salts, acids, alkalis) (J.V. Cruz *et al.*, 2015).

- **Organic pollution**

Water resources are negatively impacted by wastewater that has organic materials or organic suspensions in it. Precipitating suspensions cover the bottom and prevent microorganisms involved in the process of water self-purification from developing or functioning. When these sediments decompose, hazardous and destructive molecules, including hydrogen sulfide, can form, contaminating the entire river's water. Furthermore, the presence of suspensions prevents light from entering the water and inhibits the photosynthetic process (Ellen *et al*., 2016). Every impurity that somehow lowers the oxygen level in the water has a negative impact. Fats, oils, and lubricants, or surfactants, create a film on the water's surface that prevents gas exchange between the water and the atmosphere and lowers the water's oxygen saturation level. Industrial and domestic wastewater are released into rivers along with a significant amount of organic particles, the majority of which is not common of natural waters. Increasing pollution of water bodies and drains is observed in all industrial countries (Eline *et al*., 2019).

Organic waste that decomposes in water can provide a habitat for pathogenic organisms. Water that has been contaminated by organic waste is essentially not suitable for drinking and other uses. Household waste is hazardous due to its high oxygen need during decomposition as well as the fact that it is the source of several human diseases, including cholera, dysentery, and typhoid fever. Large amounts of domestic wastewater may cause the soluble oxygen content in the reservoir to drop below the required level for the survival of marine and freshwater species (Mostafalou *et al*., 2016).

- **Inorganic pollution**

Several chemical substances that are hazardous to aquatic life are the primary inorganic (mineral) contaminants of fresh and marine waters. Arsenic, lead, cadmium, mercury, chromium, copper, and fluorine are all present in these compounds. The majority of them enter the water due to human activity. Phytoplankton absorb heavy metals, which are then transferred to more complex species farther up the food chain (Eline, *et al.*, 2019).

Wastes containing mercury, lead, copper are localized in certain areas off the coast, but some of them are carried far beyond the territorial waters. Mercury pollution significantly reduces the primary production of marine ecosystems, inhibiting the development of phytoplankton. Wastes containing mercury typically accumulate in the bottom sediments of bays or river estuaries. It continues to migrate while also accumulating methyl mercury and becoming part of the food chains of aquatic organisms (Cláudia, *et al*., 2016).

2.3. Micropollutants in water and wastewater treatment plants

Overall, chemical, and biological micropollutants are present in wastewater treatment plants (WWTPs) , which should make these micropollutants easier to tackle and diminish the rate of their release into the environment. Literature surveys on the occurrence of various emerging pollutants in effluents from Sewage Treatment Plants (SPTs) or WWTPs reaching the natural surface waters have discussed an attenuation of their concentration in the natural receptors due to migration or retention by sorption, volatilization, or dispersion, with transfer from one environmental compartment to another (Gavrilescu M., 2015). Data on the occurrence and concentrations of some pharmaceuticals in effluents from STPs, WWTPs and surface waters, gathered from a literature survey (Pal A., 2010) show that emerging pollutants (EP) concentrations in effluents fluctuate widely, most probably due to different doses applied in various regions and inconsistent efficiency of wastewater treatment. Nevertheless, information concerning the nature, variability, transport, and fate of these compounds in wastewater and

treatment facilities must be improved, because knowledge in this area is still limited. There are few studies devoted to monitoring and understanding the processes involved in conventional or innovative wastewater treatment in eliminating or reducing the concentrations of a large diversity of emerging pollutants at wastewater facilities since most of them are not biodegradable, the conventional water treatments cannot eliminate these pollutants, resulting in an increase on the amount of pollutant reaching the user through bioaccumulation over time (Mostafalou, 2016). When these pollutants are found at low concentrations, on the microgram levels (μg/L) or nanogram levels (ng/L), they can be considered as emerging micropollutants. The concern with these micropollutants is due to being persistent and even in low amounts they can cause serious damage to organisms with which they have contacted (Viali, 2014).

2.4. Legislation on Micropollutants

In 2013, the European Union's Directive 2013/39/EU established a Watch List, which indicates potential water pollutants that should be temporarily monitored in surface waters to obtain a high-quality Union-wide dataset. It is crucial to properly assess the risk that such pollutants pose to the aquatic environment. The Watch List 1, presented in table 1 was published in 2015 (Commission Implementing Decision (EU), 2015), and included ten substances or groups of substances. Reviewing Watch List 1 resulted in the Watch List 2 (Commission Implementing Decision (EU) and Commission Implementing Decision, 2018) where the Commission removed five substances or groups of substances (diclofenac, the herbicides oxadiazon and triallate, the sunscreen ingredient 2-ethylhexyl-4-methoxycinnamate and the industrial compound 2,6-di-tert-butyl-4-methylphenol) and included three new substances (the pesticide metaflumizone and the two antibiotics amoxicillin and ciprofloxacin). The European One Health Action Plan against Antimicrobial Resistance (AMR) (health, 2020) supports, among others, the use of the Watch List to improve knowledge and to assess the risks to human and animal health posed by the presence of antimicrobials in the environment.

Table 1 - Micropollutants including pharmaceuticals, antibiotics and hormones included in EU Watch List 1 and Watch List 2.

Watch List 1 2015	Compounds	Watch List 2 2018
Empty Cell	Pharmaceuticals	
X	Diclofenac	–
–	Ciprofloxacin	X
–	Amoxicillin	X
X	Macrolide antibiotics (Erythromycin, Clarithromycin, Azithromycin)	X
Empty Cell	Synthetic and natural hormones	
X	Estrone (E1)	X
X	17-Beta-estradiol (E2)	X
X	17-Alpha-ethinylestradiol (EE2)	X
Empty Cell	Sunscreen ingredients	
X	2-Ethylhexyl 4-methoxycinnamate	–
	Pesticides	
X	Methiocarb	X
Empty Cell	Herbicides	
X	Tri-allate	–
X	Oxadiazon	–
Empty Cell	Insecticides	
X	Neonicotinoids (Imidacloprid, Thiacloprid, Thiamethoxam, Clothianidin, Acetamiprid)	X
–	Metaflumizone	X
Empty Cell	Industrial compounds	
X	2,6-ditert-butyl-4-methylphenol	–

To conclude, the substances on the Watch Lists are chosen in order to generate and preserve high-quality monitoring data for determining the dangers they pose at the EU level. A chemical may be removed from the Watch List if sufficient, high-quality data from monitoring across the EU have been gathered to permit an accurate risk assessment; otherwise, the substance must stay on the list. The specific requirements that must be met for chemicals to be removed from the Watch Lists are outlined in JRC Technical Reports - Review of the First Watch List under the Water Framework Directive and Recommendations for the Second Watch List. (Loos., 2018).

3. Pharmaceuticals as water pollutants

3.1. Classification of pharmaceuticals

Pharmaceuticals are substances with pharmacologically active components that are used to treat, diagnose, and prevent diseases as well as to alter the body's physiological function. Typically, prior to application their negative effects on both human and animal health were rigorously examined in practice. However, it is only recently that scientists have started to become interested in the potential environmental impact of the production and widespread use of pharmaceuticals. Table 2 shows some of the various classes of drugs, namely anti-inflammatories, antibiotics, antidepressants, analgesics, lipid regulators, anticancer, among other drugs (Manvendra et a*l*.,2019).

Table 2 - Some of the classes of pharmaceuticals.

Class of pharmaceuticals	**Example of compounds**	**Reference**
Anti-inflammatories	Acetylsalicylic acid; mefenamic acid; carprofen; ketoprofen; diclofenac; ibuprofen; naproxen; indomethacin	Jiang *et al*. ,2013
Antibiotics	Amoxicillin; ciprofloxacin; cephalexin; penicillin; lincomycin; sulfapyridine; trimethoprim; ofloxacin; chlorotetracycline	Jiang *et al*., 2013
Antidepressants	**Sertraline;** citalopram; diazepan; fluoxetine; aminoantipyrine; paroxetine; antipyrine; duloxetine; mirtazapine	Gavrilescu *et al*., 2015
Analgesics	Paracetamol; codeine; fenoprofen; metamizole	Silva and Collins, 2011
Lipid regulators	Clofibrate; acebutolol; fenofibrate; gemfibrozil	Gavrilescu *et al*., 2015
Hormonal contraceptives	Desogestrel, mestranol, tinilestradiol	Birkholz *et al*., 2014
Anticancer	Cyclophosphamide; ifosphamide	Gavrilescu *et al*., 2015
BetaBlockers/ Antihypertensives	Starchacid; betaxolol; chlorothiazide; furosemide; propranolol; diltiazem; atenolol	Silva and Collins, 2011
Antidiabetics	Gliclazide; metformin; glibenclamide	Gavrilescu *et al*., 2015

3.2. The case study of sertraline

Depression is one of the most common mental diseases in the world which has significantly negative effects on the whole life of patient and may also resulted in self-injury and suicide. Presently, Sertraline has become one of the most frequently prescribed drugs for depression treatment it is the generic form of the brand name drug Zoloft which was launched in 1991 (Lotfi *et al.*, 2017). However, once in the water, these compounds interfere with the removal process in wastewater treatment facilities.

The structure of sertraline is shown in Figure 1. It belongs to the class of drugs known as selective inhibitors of neuronal serotonin (5-HT) reuptake, which stimulates the effects of serotonin: possible paradoxes of 5-HT that result in a relative increase in 5-HT1 receptors (Esteves, 2015). It has a very weak effect on the neuronal reuptake of dopamine and norepinephrine. It is devoid of stimulant sedative or anticholinergic activities or cardiotoxicity. The highest daily dose permitted for sertraline is 200 mg, and it is offered on the pharmaceutical market in dosages of 25, 50, and 100 mg in coated or uncoated tablets.

One of the antidepressants that is most frequently administered in recent years is sertraline. Therefore, it is not shocking that it is frequently found in wastewater, surface water, sediments, and effluent treatment facilities (Lotfi *et al.*, 2017).

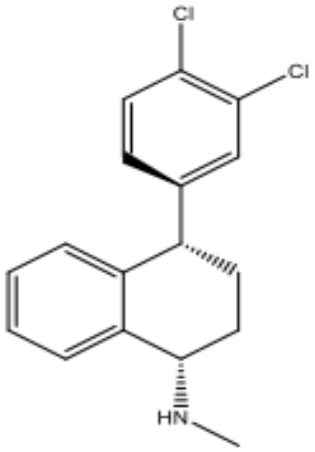

Figure 1 – Chemical structure of sertraline (Esteves, 2015).

Sertraline hydrochloride has the chemical formula $C_{17}H_{18}Cl_3N$, a molar mass of 342.7 g/mol, and the IUPAC designation cis-(1S,4S)-4-(3,4-dichlorophenyl)-1,2,3,4-tetrahydro-N-methyl-1-nanphthalenamine (Zhou and Foley, 2004). The sertraline's pKa is 9.16, its partition coefficient is 5.51, and its water solubility is 3.8 g/L (Almarsson, 2003).

When exposed to various circumstances, such as exposure to specific solvents (water, methanol, ethanol, and isopropanol, among others), exposure to various degrees of relative humidity, and exposure to high temperatures, the marketed polymorph can easily transform into other polymorphic forms. Due to the drug's production features, it is therefore feasible to identify more than one polymorphic form in the commercial formulation. This underlines the significance of doing a final product examination to determine whether any transitions happened throughout the production process.

According to Farias and Carneiro (2014), the wet granulation process, in which water is added to the process for the formation of granules and this granulation is allocated in a fluidized bed, facilitates the change in crystalline phase. This process includes passing through the drying process followed by the Kiln process drying, where moisture is evaporated by heat exchange through hot air currents. As a result, it's possible for multiple polymorphic forms to coexist in the same formulation. According to certain researchers (Farias *et al*., 2016), who demonstrate that moisture present in excipients improved drug hydration of Ezetimibe, polymorphic transitions can still happen as a result of moisture transfer between excipients and the active pharmaceutical ingredient (API).

4. Removal of pollutants from water

4.1. Main removal methods

All water treatment techniques that are specifically designed to remove emerging pollutants result in one of two outcomes: either the removal of pollutants through the adsorption by a particular component (adsorbent), or the decomposition of pollutants to produce a less complex substance while losing the properties of the original pollutant. This pattern allows for the division of removal processes into two categories: degradation and adsorption.

With different types of chemicals and treatment conditions, each approach exhibits variable efficacy. To establish a method of removal, considering the state of the aquatic environment in a specific area, this requires the analysis of previous studies to choose the proper procedure and reagents.

4.2. Removal of pharmaceuticals using adsorption

Adsorption is one of the most popular technologies today because it is effective at treating both water and wastewater when the chemical contamination of the water includes both organic and inorganic pollutants, which are frequently resistant to biological degradation, or when other methods are ineffective (Nascimento *et al*., 2014). Toxic compounds can be present in liquid and gaseous effluents. Thus, it is important to remove them in order to reduce the environmental impact. This is where the adsorption process comes in. Because the mixture's molecules are drawn to the adsorbent surface by unequaled pressures for a brief period of time, the adsorption process occurs (Coelho *et al.*, 2014).

According to Metcalf and Harrison (2017), activated carbon is widely used in the removal of micropollutants. This material is made from a variety of organic materials, including wood, olive stones, animal bones, shells from nuts like almonds, walnuts, and coconuts, as well as wood with a high carbon content. The pyrolysis process causes the material to become porous. The coal source material, the preparation, and the kind of the activating agents all have a significant impact on the coal's adsorption properties, which include surface area, regeneration characteristics, and pore size distribution. There are also several variations that may occur (Matos, 2015).

4.2.1. Biomass-based adsorbents

- **Activated carbon**

Activated carbon (AC) is a porous material that is created on an industrial scale from a variety of carbon-containing organic sources, including charcoal, coal coke, petroleum coke, coconut shell, and other things.,. Pharmaceuticals and personal care products (PPCPs) can be removed using AC, a popular adsorbent used in water treatment. It is available as granular (GAC) and powdered (PAC) forms (Jiankong, 2016).

Adsorbent activation can be accomplished by a variety of physical and chemical techniques. In chemical activation, organic material interacts with activating substances like H_3PO_4, $ZnCl_2$, NaOH, KOH, NH_4Cl, K_2CO_3, etc. The key to activation is to create pores in the closed carbon substance. This is accomplished either thermochemically (pre-impregnated with a solution of zinc chloride, potassium carbonate, or some other compounds and heated without air), or by treatment with superheated steam, carbon dioxide, or a mixture of the two at a temperature of 800-850°C (Jiang,2016)

It is theoretically challenging to obtain an agent with such a temperature, Saturated vapors and a limited amount of air can be combined to create the required conditions. Part of the carbon burns out, and the required temperature is reached in the reaction space.

The yield of activated carbon in this process has considerably decreased. The best brands of activated carbon have a specific surface area per gram of 1800–2200 m^2. It is possible to obtain macro, meso, and micropores.

The carbon must be created with various ratios of pore diameters depending on the size of the molecules that must be retained on the surface (Krzeminski *et al.*, 2019).

- **Water-soluble protein**

A technique for preparing water-soluble protein from *Moringa stenopetala* seeds was described by Kebede *et al*. in 2018. Petroleum ether was incorporated into the seed powder after 30 minutes of stirring. By using filtering, solid seed material was separated. The water-soluble protein was extracted by dissolving the recovered solid in ultra-high purity water and stirring for 30 min. Ammonium sulphate was used to precipitate the proteins from the aqueous extract in the filtrate, and salt was added until saturation. To get rid of the insoluble material, the precipitated protein was filtered, redissolved in water, and then filtered again. After that, a

cellulose membrane was used to dialyze the protein solution. Following the freeze-drying of the pure protein, a white powder was produced and kept at room temperature until needed. The removed protein from the sample shows a notable removal effectiveness (up to 86%) against a group of 23 pharmaceuticals (carbamazepine, ibuprofen, ketoprofen, kenoprofen, diclofenac) in initial concentration from 1 to 5 ppm (Kebede *et al*. in 2018).

- ## Graphene oxide

Graphene oxide (GO), according to Ninwiwek *et al*., 2019, was produced by oxidizing natural graphite. Ethylene glycol was used to dissolve both GO and Fe_3O_4 in order to produce magnetite particles (mGO). Glutaraldehyde was added after the solutions had been combined. At room temperature, the mixture was stirred for ten hours. After centrifugation and deionized water elution, the product was recovered. Remaining water was removed by drying the product in an oven at 105 °C for 24 hours. Tetraethyl orthosilicate was combined with graphene oxide to create the silica-magnetic graphene oxide nanocomposite (mGO-Si) (Ninwiwek *et al*., 2019).

- ## Biological residues

Methods utilizing organic waste, such as walnut shells, olive stones, apricot shells, bamboo waste, plant sludge (Teixeira et al., (2019), and others, are of significant interest in terms of both economic and environmental issues, due to the fact that they were inexpensive and available. The results shown in Table 4 indicate how effectively pharmaceutical pollutants can be eliminated from aqueous matrices. Table 3 lists a few techniques for chemically activating each of the adsorbents made from organic waste, along with details on their properties such particular pore size and adsorption capacity. The adsorption capacity for the same adsorbent can vary significantly depending on the activating agent selected. This is seen in the research by Boudrahem *et al*. (2019). When phosphoric acid was used instead of zinc chloride, the adsorbent made of olive stone has achieved its excellent characteristics. This tendency can also be seen in studies on the utilization of walnut shells by Teixeira *et al*. (2019) and Nazari *et al*. (2016).

Table 3 - Literature review on removal of pharmaceutical drugs by adsorption process.

Operation process	Drugs	Adsorption	Matrix	Experience Time (min)	Reactor Volume (mL)	pH	T(°C)	Capacity (mg/g)	Significant Findings (mg/g)	References
Batch adsorption	Ibuprofen Naproxen Diclofenac	Green-synthesized copper nanoparti-cles (Cu NPs)	Wastewater	60	1000	4,5	25	33.9 33.9 36	The percentage of removal of IBU for about 74.4%, for DIC about 91.4% and NPX about 86.9%	Husein *et al.*, 2019
	Naproxen	Ag-RGO Nano-composite film	Aqueous solution	3	50	4.5	25	229.25	92.62% of removal	Mondal *et al.*, 2020
	Antidepressant (Nortriptyline)	Nanoparticle- Loaded biowaste	Aqueous solution	180	50	7	46		67.4% of removal	Kovo *et al.*, 2021
	Diclofenac	Cyclamen Presicum tubers Activated carbon	Aqueous solution	120	50	6	15	606.78	Elimination of 81% when DIC concentration was 70mg/l and 0.7g CTAC	Jodeh *et al.*, 2014
Column adsorption	Ketoprofen Naproxen ibuprofen	**Olive waste cake**	Deionized water	11 12 19	300	7	25	24.69 56.17 10.83	90.45% of removal for NPX 88.40% of removal for ketoprofen 70.07% of removal for IBU	Baccar *et al.*, 2012
		AC from goose-berry seed-shells	WWTP	15	50	4.40		154.98	61.99% of removal	Mondal *et al.*, 2020

4.2.2. Effect of the adsorption operating conditions on the removal process

Table 4 summarizes experimental parameters for adsorption procedures used in research that evaluated employing AC based on organic waste as adsorbents. Adsorption efficiency is influenced by a number of factors, including pH, adsorbent quantity, adsorbate concentration, contact time, temperature, and carbon particle structure.

Table 4 - Comparative pharmaceuticals removal effectiveness using activated carbons derived from organic waste.

Precursor	**Adsorbate**	**Initial concentration (mg/L)**	**Adsorption capacity (mg/g)**	**Removal efficiency (%)**	**Reference**
Olive stone	Tetracycline Sulfamethazine Amoxicillin	100	183 190 156	up to 100	Boudrahem *et al*., 2019
Olive stone	Amoxicillin	100	68	n/a	Limousy *et al*., 2017
Olive waste cake	Ibuprofen Ketoprofen Naproxen	10 20 20	10.83 39.52 10.83	70 88 90	Baccar *et al*., 2012
Plant sludge	Tetracycline	700	672	n/a	Rivera-Utrilla *et al*., 2013
Potato peel	Diclofenac	100	68.5	70	Bernardo *et al*., 2016
Potato peel	Dorzolamide Pramipexole	50	60 66	80 88	Kyzas *et al*., 2014
Walnut shell	Sulfamethoxazole Metronidazole	40	107 127	n/a	Teixeira *et al*., 2019
Tea waste	Caffeine	50	27	77	Keerthanan *et al*., 2020
Sewage sludge, Fish waste	Carbamazepine	100	37.2	96	Nielsen *et al*., 2015
Plant sludge	Tetracycline	700	672	n/a	Rivera-Utrilla *et al*., 2013

- **Effect of raw materials carbonization temperature**

Hashemian *et al*. (2014) described the use of processed orange peel and almond shell as an efficient adsorbent for 2-picoline adsorption. It has been found that the temperature of carbonization has a considerable impact on the effectiveness of pharmaceutical removal. The range of pre-treated orange and almond peel samples underwent carbonization at various temperatures ranging from 300 to 1200 °C. When the activation temperature was raised, the removal effectiveness of 2-picoline rose up to 700 °C before declining at higher temperatures. For instance, 2-picoline elimination using carbon produced from almond shells at 300 °C was 27.6% and up to 90% utilizing carbonized adsorbent at 700 °C. Surface area of activated carbon grew between carbonization temperatures of 200 and 700 °C, but it decreased between 700 and 1200 °C. At 700°C, and for both almond shell and orange peel raw-materials, the most porous structure and adsorption capacity were also attained (Saedeh *et al*., 2014).

- **Effect of activation agent**

Hayat *et al*. (2015) provided a description of another technique for turning olive stone waste into activated carbon used to remove ibuprofen and amoxicillin from aqueous solution. As activating agent, phosphoric acid was utilized in a 3:1 mass/mass ratio to the precursor. Foe the pyrolysis conditions, a nitrogen flow rate of 300 mL/min, process temperature of 450°C, and process duration of 2.5 h was used. Following this procedure, the resulting carbon was cleaned with distilled water and overnight-dried at 60°C. The chosen range of particle size was 0.212 to 0.710 mm.

In the next two studies, KOH was used to chemically activate a precursor to create activated carbon using discarded olive stone. According to Martinez *et al*. (2006), the precursor was milled to a particle size of 1-3 mm after being dried at 100°C. Then, carbonization was carried out instantly for one hour at 600°C in a muffle furnace. Two different KOH solutions (50 and 75%, w/w) were used in a 1:1 ratio to the char to produce the chemical activation. The mixture was first dehydrated at 300 °C for three hours before being pyrolyzed in a nitrogen flow at 900 °C. The obtained 1-2 mm-sized particles were cleaned and dried at 100°C for 2 hours (Hayat *et al*.,2015).

According to Alslaibi *et al.,* 2012, olive stone precursor was cleaned and dried at 105°C for 24 hours, and then ground to a particle size of 1-4.75 mm. KOH pellets were used to impregnate the 30 g of precursor in a 1.25:1 ratio. KOH pellets were then dissolved using distilled water.

For 24 hours, impregnation was given at room temperature. The samples were dried in the sun for three days after being impregnated. With nitrogen flowing at 150 mL/min for 3 hours at 600°C, activation was completed. The obtained activated carbon was washed using a solution of HCl (0.1M) and distilled water at 70°C. The materials were dried at 110°C for 24 hours as the last stage in the manufacture of the adsorbent (Tamer *et al*.,2014).

In conclusion, it is possible to recognize common characteristics of the preparation process for olive stone-based adsorbents by considering the methodologies mentioned above. In order to fill the precursor with an activation agent, processing is required. Drying is a component of this step. The temperature ranges from ambient to 100–110°C can be used to provide it, according to studies. Increasing temperature affects the time needed for the process. Precursor must then be grounded to a chosen particle size, which might range from μm to mm.

The pyrolysis process and impregnation with an activation agent are both parts of the chemical activation. By raising the temperature (up to 110°C), the impregnation can also be expedited up to 7-9 hours. For pyrolysis, a nitrogen flow of 150 mL/min and a temperature of up to 600 °C are needed. The duration of the process varies from 1 to 3 hours. The obtained activated carbon needs to be cleaned with distilled water and a hydrochloric acid solution before being dried for a few hours at a temperature of up to 100°C (Pratibha *et al*,.2016).

As showed in Table 5 the impact of an activation agent on bamboo waste microwave aided activated carbon as discussed in Reza *et al*., 2014. To select the optimal activation agent, the effects of various activating agents, including H_3PO_4, KOH, NaOH, HCl, and $ZnCl_2$, were investigated. The activating agents, such as H_3PO_4, KOH, NaOH, and HCl, were discovered to have poor adsorption capacity and to be less prone to volatile loss. However, $ZnCl_2$ activation creates porosity and expands the adsorbent's surface area. $ZnCl_2$ is one of the most commonly utilized activating agents due to its ability to increase yields and surface area.

Two activating agents (H_3PO_4 and $ZnCl_2$) were used to create olive stone activated carbon in Boudrahem *et al*., 2019 study, and properties of the obtained AC were compared. The H_3PO_4 OSAC (Olive Stone Activated Carbon) has shown to have a much greater adsorption effectiveness than $ZnCl_2$ OSAC (97.58 mg/g sorption quantity against 42.01 mg/g).

Table 5 - Comparison of specific surface area and adsorption capacity of different adsorbents using different activation agents.

Precursor	Adsorbate	Activation agent	Specific surface area (m^2/g)	Adsorption capacity (mg/g)	References
Bamboo waste	Ibuprofen	$ZnCl_2$	120	278	Reza *et al*., 2014
Laminaria digitata algae	Ketoprofen Aspirin	NaOH	799	443 970	Ouasfi *et al*., 2019
Olive stones	Tetracycline Sulfamethazine Amoxicillin	H_3PO_4	1254	186	Boudrahem *et al*., 2019
Olive stones	Tetracycline Sulfamethazine Amoxicillin	$ZnCl_2$	1194	42	Boudrahem *et al*., 2019
Olive stones	Amoxicillin	H_3PO_4	1174	68	Limousy *et al*., 2017
Plant sludge	Tetracycline	NaOH	163	672	Rivera-Utrilla *et al*., 2013
Walnut shell	Cephalexin	$ZnCl_2$	1452	233	Nazari *et al*., 2014
Apricot shell	Tetracycline	H_3PO_4	307	308	Marzbali *et al*., 2016
Sugarcane	Ibuprofen	H_3PO_4	557	14	Chakraborty *et al*., 2018

4.3. Adsorption kinetics study

Kinetic analysis of an adsorption process provides information on the solute uptake rate. It defines the residence time necessary for the adsorption reaction to be completed and, as a result, the scale-up of an adsorption equipment. Adsorption typically consists of three steps that happen in succession: (1) external diffusion of the adsorbate molecule across the liquid film surrounding the adsorbent particles to reach the adsorbents' surfaces; (2) internal diffusion of

the adsorbate molecule through the adsorbent pores to interior sites; and (3) adsorption and desorption between the adsorbate molecule and the adsorbent active sites (i.e., reaction). The most suitable kinetic models to use are pseudo-first- and pseudo-second order models if the interaction between the adsorbate molecule and adsorbent active sites is the rate-limiting step. Therefore, these models might offer details which help in clarifying the adsorption process's mechanics. However, several studies have been published in the literature that, despite the fact that the diffusional stages were the rate-limiting steps, the kinetic analysis was conducted using the pseudo-first- and pseudo-second-order models due to their simplicity.

To discover the true mechanism in such circumstances, it is crucial to incorporate additional analytical techniques (Xuan, 2019). The literature-based adsorption kinetics models that were used to the adsorption of PPCPs on AC are shown in Tables 6.

4.3.1 Pseudo-first-order model

The pseudo-first-order model is believed to be the earliest model pertaining to the adsorption rate based on the adsorption capacity. It was initially presented to describe the kinetic process of liquid-solid phase adsorption of oxalic acid and malonic acid onto charcoal. However, it later proved to be appropriate for kinetic analysis of various adsorption applications such as adsorption of pollutants from wastewater. As Tables 6 shows, the pseudo-first-order model has often been used to describe the kinetics of adsorption of emerging pollutants on AC, and its wide application is attributed to its simplicity. The pseudo-first-order kinetic model can be presented as follows:

$$ln(q_e - q_t) = lnq_e - k_1 t \quad (1)$$

where *qe* and *qt* (mg/g) are the adsorption capacities (i.e. the amounts of the organic pollutant adsorbed) at equilibrium and time t (min), respectively. k_1 (min^{-1}) is the pseudo-first order rate constant, and it can be obtained from the slope of the regression line on the plot of *ln(qe −qt)* against time (Xuan, 2019).

4.3.2 Pseudo-second-order model

Pseudo-second-order model can be expressed as follows:

$$\frac{t}{q_t} = \frac{t}{q_e} + \frac{1}{k_2 q_e^2} \quad (2)$$

The parameter k_2 (g/mg min) is the pseudo-second-order rate constant.

Table 6 - Adsorption isotherms and kinetic models applied in studies using organic waste based activated carbon.

Precursor	Adsorbate	Adsorption isotherm models	Adsorption kinetic models	Reference
Olive stones	Tetracycline Sulfamethazin Amoxicillin	Freundlich, Langmuir and Redlich–Peterson	Pseudo-first-order, Pseudo-second-order	Boudrahem *et al*., 2019
Olive stones	Amoxicillin Ibuprofen	Freundlich and Langmuir	Pseudo-second-order model	Mansouri *et al*., 2015
Olive stones	Amoxicillin	Freundlich, Langmuir, Redlich–Peterson, Sips, Toth and Temkin	Pseudo-first-order, Pseudo-second-order models	Limousy *et al*., 2017
Plant sludge	Tetracycline	Freundlich and Langmuir	n/a	Rivera Utrilla *et al*., 2013
Bamboo waste	Ibuprofen	Freundlich, Langmuir, Temkin, and Dubinin–Radushkevich	Pseudo-second-order model	Reza *et al*., 2014
Apricot shell	Tetracycline	Freundlich, Langmuir and Temkin	Pseudo-first-order, Pseudo-second-order models	Marzbali *et al*., 2016
Walnut shell	Sulfamethoxazole Metronidazole	Freundlich and Langmuir	n/a	Teixeira *et al*., 2019

5. Technical description and procedures

There are two key stages to the experimental section of this study. The preparation of the olive stone adsorbent is the first stage. In the second phase the removal of sertraline by adsorption process is presented.

5.1. Chemicals and raw materials

The following chemicals were used during this work:

- Commercial tablet of Sertraline (pills of 100 mg).
- Olive pits collected from one of Bragança's local olive oil producer.
- Ultrapure water
- H_2SO_4 10% Sigma-Aldrich.
- NaOH 0.1 M Sigma-Aldrich.
- Ethanol +98%, Sigma-Aldrich.

5.2. Equipment and materials

The following equipment was used in this work:

- UV-Vis Jasco V-730
- pH meter HANNA edge
- Ultra-centrifugal mill RETSCH ZM 200
- Shaker incubator SHELL LAB
- Stove Scientific
- Incubator
- Oven
- Stirring plat
- Filter
- Analytical Balance
- Water System, Ultrapure Millipore® Synergy
- Syringe Filter 0.45 mm

5.3. Preparation of the adsorbent from olive stones

The raw material used in this work were olive stones collected from one of Bragança's local olive oil producer (Casa de S. Amaro, Mirandela). The original olive stones were stored in the laboratory at room temperature until the moment of the chemical and physical activation. For the preparation of the activated and carbonized adsorbent, the following steps were executed:

1) Grinding up the olive stones to reach an average diameter of 0.25 mm.

2) Activation of the pulverized solid by mixing it with a 10% (wt/wt) sulfuric acid aqueous solution.

3) Washing the filtrated solid with distilled water.

4) Drying the solid at 110^{o}C using an oven for 24 h.

5) Carbonization of the solid using an oven at 550°C for 90 min.

- **Activation of the adsorbent**

The grinding of the olive pit was done with an ultra-centrifugal mill ZM 200 of the brand Restsch GmbH (Figure 2), with a rotor of 12 teeth and diameter up to 99 mm with a maximum speed of 1000 rpm.

Figure 2 - Laboratory mill used in the grinding of the olive pit

A 10% aqueous solution of H_2SO_4 in a 1:3 ratio (wt/wt) was added to the adsorbent in 250 mL precipitation beaker, then measure using an analytical balance 50 g of granulated adsorbent and add 150 mL of acid solution. the procedure was repeated with 50 g of 0.25 mm adsorbent, adding 150 mL of acid solution and then the mixture was left in stirring (stirring plate and magnetic bar) in the fume hood for 24 h. Later the solution was filtered in funnel with a porous glass plate of "1 medium coarse "porosity and then the adsorbent was washed with at least 100 mL of distilled water and dried at room temperature overnight. The dry adsorbent was placed in an incubator for 24 hours at 110 °C. then the solid is carbonized in a muffle furnace at 550 °C for 1.5 hours.

5.4. Characterization of the adsorbent

The textural properties of the materials were determined from N_2 adsorption–desorption isotherms at 77 K, obtained in a Quantachrome NOVATOUCH XL 4 adsorption analyzer. The degasification of the materials was conducted at 120 °C during 16 h and then BET, Langmuir specific surface area (S_{BET}, $S_{Langmuir}$) was determined using BET and Langmuir methods. The external surface area (Sext) and the micropore volume (V_{mic}) were obtained by the t-method (thickness was calculated by employing ASTM standard D-6556-01). The microporous surface area (S_{mic}) was determined as the subtraction of Sext from SBET and the average pore width (W_{mic}) by approximation (W_{mic}=2.2). The total pore volume (V_{Total}) was determined at p/p0 = 0.98. Calculations of those methods were all done by using TouchWinTM software v1.21.

- **pH**pzc **determination**

The pHpzc is the pH on zero point of charge, or the point at which the net charge of the adsorbent is zero.

The experimental procedure was as follows:

1) To prepare 8 solutions of 25.00 mL of 0.01 M Sodium Chloride (NaCl).

2) To adjust the pH of the different solutions (2, 3, 4, 5, 6, 8, 10 and 12) with Sodium Hydroxide (NaOH) or Hydrochloric Acid (HCl) solutions.

3) To add 0.15 g of adsorbent to each solution.

4) To carry out the tests on an orbital shaker (20 ˚C, 320 rpm, 24 h)

5) To measure and record the new pH values.

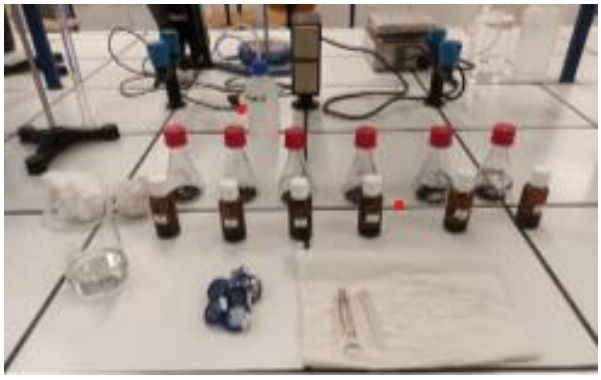

Figure 3 - Point of Zero Charge experiments.

- **Number of Acidic and Basic Sites**

The acidic and basic sites present in the surface of the adsorbent consist of several functional groups which contain H^+ and OH^- ions, respectively, which allows for the formation of electrostatic bonds between the adsorbent and the adsorbate.

The characterization of acidic and basic surface sites is made by the following procedure:

1) Preparing 6 flasks of 100 mL with stopper with 0.20 g of adsorbent, 3 with 25.00 mL of 0.02 M Sodium Hydroxide (NaOH) and 3 with 25.00 mL of 0.02 M Hydrochloric Acid (HCl).

2) Carrying out the tests in an incubator (25 °C, 200 rpm, 48 h)

Acidic Sites:

1) The solutions were filtered (wash the filters 1 time with methanol and 3 times with distilled water).

2) To titrate the solutions containing Sodium Hydroxide (NaOH), 10.00 mL of the test solution and 5 drops of phenolphthalein, with Hydrochloric Acid (HCl) solution.

3) To calculate the final concentration (mol/L) of Sodium Hydroxide (NaOH) through:

$$C_{NaOH,final} = C_{NaOH,initial} \times V_{equivalent}/V_{titled} \quad (5)$$

4) To calculate the number of acidic sites (µmol H+/g adsorbent) through:

$$N.acidic\ sites = \left(C_{NaOH,initial} - C_{NaOH,final}\right) \times V_{NaOH}/m_{adsorbent} \quad (6)$$

Basic Sites:

1) To filter the solutions (washing the filters 1 time with methanol and 3 times with distilled water).

2) Titrate the solutions containing Hydrochloric Acid (HCl), 10.00 mL of the test solution and 5 drops of phenolphthalein, with the titrant composed of the Sodium Hydroxide (NaOH) solution.

3) To calculate the final concentration (mol/L) of Hydrochloric Acid (HCl) through:

$$C_{HCl,final} = C_{HCl,initial} \times V_{equivalent}/V_{titled} \quad (7)$$

4) To calculate the number of basic sites (mol OH^-/g adsorbent) through:

$$N.basic\ sites = \left(C_{HCl,initial} - C_{HCl,final}\right) \times V_{HCl}/m_{adsorbent} \quad (8)$$

- **Fourier Transform Infrared Spectroscopy**

Fourier Transform Infrared spectroscopy was the selected instrumental technique to chemically characterize the different treated adsorbents, namely the just carbonized adsorbent (AC) and the activated and carbonized adsorbent (AAC). This technique allows for the identification of functional groups and interaction bonds present in the adsorbent's surface.

The FT-IR characterization was done using a JASCO equipment, model Spectrum Two, equipped with an ATR module.

- **Surface area and pore volume**

The adsorbents were submitted to superficial area and porous volume analysis using a volumetric adsorption analyzer, Surface Analyzer Quantachrome Nova Touch Pore Size Analyzer, as presented in Figure 4, at -196.0 °C. Initially, the adsorbent samples underwent a degassing and drying process for 24 hours in a nitrogen rich atmosphere, then the analysis was performed. The obtained data was adjusted in a mathematical model of B.E.T and B.J.H to obtain the results of specific surface area, pore volume and average pore diameter.

Figure 4 - Surface Analyzer Quantachrome Nova Touch Pore Size Analyzer.

5.5. Quantitative analysis of sertraline using UV-Vis

All reagents and materials used were of analytical reagent grade. Sertraline reference standard was kindly provided by Sandoz Pharmaceutica. solid dose formulation, commercial tablets of Sertraline Sandoz (100 mg sertraline per pill) were utilized to prepare a stock solution (200ppm) by dissolving 100 mg pill of sertraline in 500ml ultrapure water inside a volumetric flask then the suspended solution was agitated for about 30 min. This was followed by filtration through a filter paper to remove insoluble matter, therefore the solution is ready for future dilution.

A UV-visible spectrophotometer model Jasco V-730 (figure 5) with 10 mm quartz cells was utilized for spectrophotometric determinations. The pH measurements were performed by using a pH meter model HANNA edge.

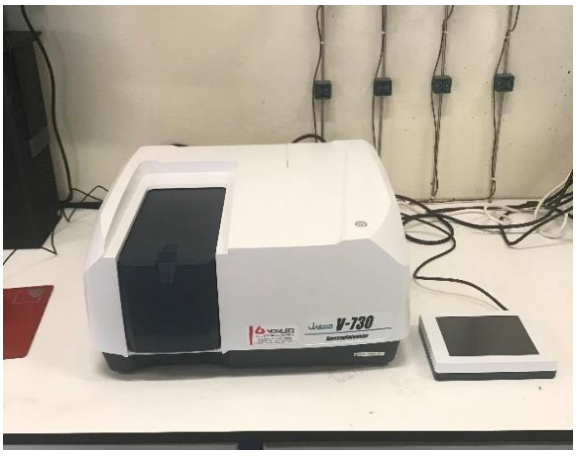

Figure 5- UV-Vis spectrophotometer Jasco V-730.

As shown in Figure 7, the results of the calibration curve for sertraline at a wavelength 230 nm, was a linear behavior with $R^2 = 0.9979$ for pH 7.

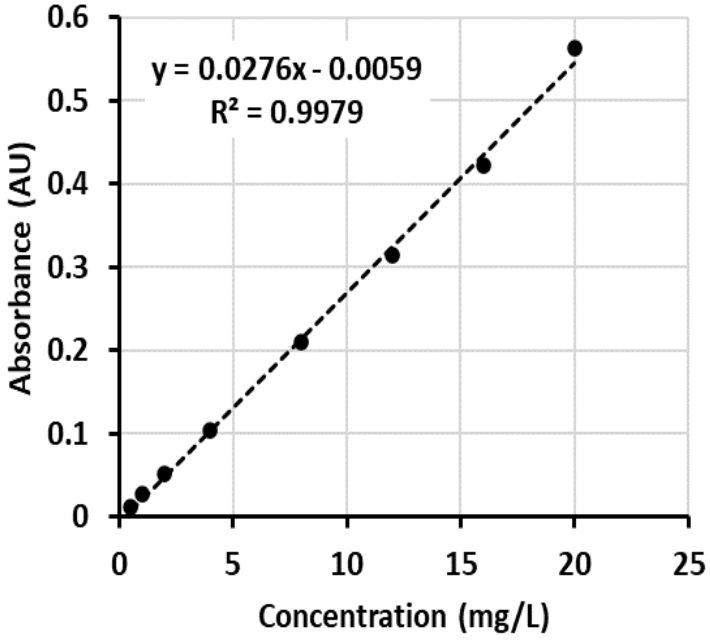

Figure 6- Results of the calibration curve for sertraline.

5.6. Removal of sertraline by adsorption using the batch method

The focus of this research was adsorption. All experiments were carried out in a batch mode, during these tests it is possible to see the variation in the removal of sertraline, all Erlenmeyer's are placed inside the incubator under a moderate stirring (150 rpm) at different temperatures. After incubation time the samples were analysed with UV-Vis at a wavelength of 230 nm. To study the efficiency of the adsorbent in sertraline removal, tests will be done with different masses of adsorbent of 10mg, 25mg, 40mg, 55mg, also with the variation of time from 10 min to 48 hours under different temperatures of 25°C, 35°C, 45°C.

Different kinetic models have been designed and used, depending on the rate-limiting stage of an adsorption process. The film diffusion model is suitable if the external diffusion step is the rate-limiting stage of an adsorption process.

In contrast, intra-particle diffusion models like the homogeneous surface diffusion model (HSDM) are more likely to be applicable if the internal mass transfer is the rate-limiting stage of an adsorption process. Finally, if the interaction between the adsorbate molecule and the adsorbent active sites is the rate-limiting step, the pseudo-first- and pseudo-second order models are the most appropriate kinetic models. Thus, these models might offer details that help to clarify the adsorption process's mechanics. Based on the literature. Table 6 describe the adsorption kinetics models applied for the adsorption of PPCPs on the activated carbon.

6. Results and discussion

6.1. Characterization of olive stone activated carbon

Table 7 and 8 present some physical characteristics of activated carbon prepared from olive stones. The results obtained show that the moisture and ash rates are suitable for industrial exploitation also many coal manufacturers obtain similar results (S. Hazrouli, 2002).

Table 7 - Textural properties of the OSAC.

S_{BET} (m^2/g)	$S_{Langmuir}$ (m^2/g)	S_{ext} (m^2/g)	S_{ext} (m^2/g)	S_{ext} (m^2/g)	V_{mic}/V_{Total} (%)	$W_{micropores}$ (nm)
409	608	16	393	213	92	2.2

Table 8 - Adsorbent chemical and physical characterization.

Acidic sites (μmol H^+/g adsorbent)	Acidic sites (μmol H^+/g adsorbent)	pH_{ZC}
877.4	44.7	3.17

- **FTIR analysis**

The FTIR analysis was performed in order to determine the functional groups present in the adsorbent surface, with the results for both adsorbents just carbonized adsorbent (AC) and the activated and carbonized adsorbent (AAC).

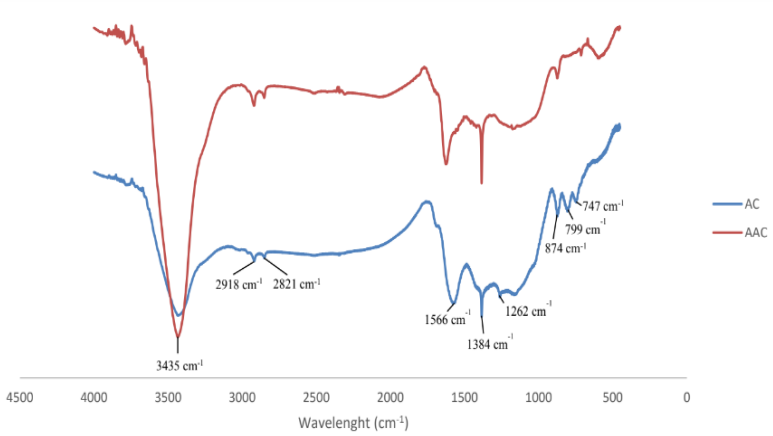

Figure 7 - FTIR analysis of AC and AAC materials.

As showed in Figure 7, it is possible to observe how the activation process affected the chemical composition of the adsorbent and it let us theorize how the change in the functional groups might influence the adsorption mechanism, with the results summarized in Table 9.

Table 9 - Functional group or bond changes with chemical activation.

Peak (cm^{-1})	Functional group or bond	Change with activation
3435	Stretching of O-H bonds in alcohols and phenols	Increased
2918	Stretching of C-H bonds in alkanes	Increased
2821	Stretching of C-H bonds in aldehydes	Increased
1566	Folding of N-H bonds in secondary amines	Decreased
1384	Folding of methyl groups (-CH3)	Increased
1262	Stretching of C-H bonds in alcohols and phenols	Disappeared
874	Not identified	Decreased
799	Folding of C-H aromatic bonds out of plane	Disappeared
747	Not identified	Disappeared

According to the changes verified in Figure 7 and Table 10, it is possible to conclude that the activation process impacts the chemical composition of the adsorbent's surface. With the activation process, an enrichment in oxygen groups, such as alcohols, is observed at the same time with a decrease in nitrogen groups, such as amines, likely an affect from the acidic nature of the sulfuric acid used on the AAC adsorbent. In addition to that, a decrease was noticed for peaks that represent C-H aromatic bonds, which indicates that the activation process promotes

the breaking of aromatic rings in favor of more simple aliphatic carbon chains, as it can be seen by the peak located at 2918 cm^{-1}.

6.2. Optimization of the main adsorption parameters

6.2.1. Contact time

The effect of contact time on removal of sertraline is shown in Figure 8. The adsorbed amount of sertraline onto the activated carbon increased with the increase of contact time, and the sertraline adsorption curves are almost of saturation type and the chemical equilibrium is reached after 48h. Adsorption capacity for sertraline showed a rapid increase in adsorption amount during the first 8 h. This fast adsorption capacity at the initial stage by OSAC indicated higher driving force (Mohamed Ali,2010). Most of the maximum uptake was attained after 20h inside the incubator. days). These results are found to be substantially higher than the ones found in the literature, particularly when compared with the study about adsorption of sertraline (Ahmed *et al*., 2012).

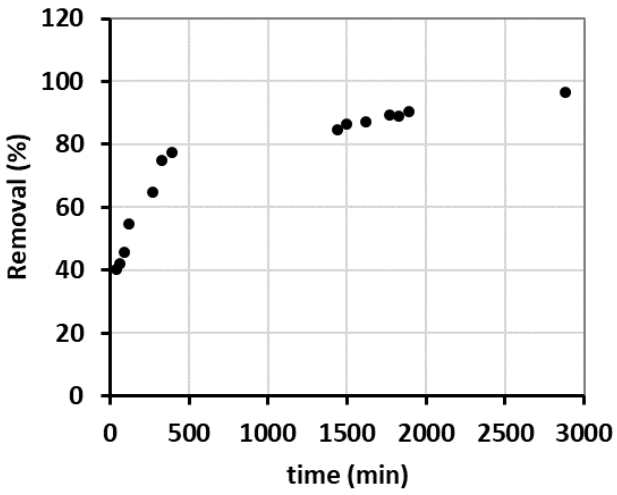

Figure 8 - Effect of contact time on the retention of Sertraline (C = 20 mg/L V= 50 mL, pH = 7, T = 25 ± 2°C, $m_{adsorbent}$ = 55 mg).

6.2.2. Effect of pH

The variation of adsorption was investigated in the pH range 3–9 using sulfuric acid and sodium hydroxide to control the effect of pH on sertraline removal was studied, using 0.25 g of ACOS and for a contacting time of 480 min to reach equilibrium. Figure 9 shows the variation of the adsorption efficiency with the change of pH. Where the optimal values of removal were seen with a pH=7, However, further studies are necessary in order to confirm the optimal pH and to pinpoint the exact equilibrium time.

The capacity of the adsorption process depends heavily on pH since it influences both the charge of the AC surface groups and the dissociation of organic molecules. The surface of AC is negatively charged when the pH exceeds the point of zero charge (pH_{PZC}). Once the pH of the solution is greater than the organic pollutant's pKa (the negative log of the acid dissociation constant or Ka value), it is simultaneously deprotonated (Ruhul *et al.*,2016).

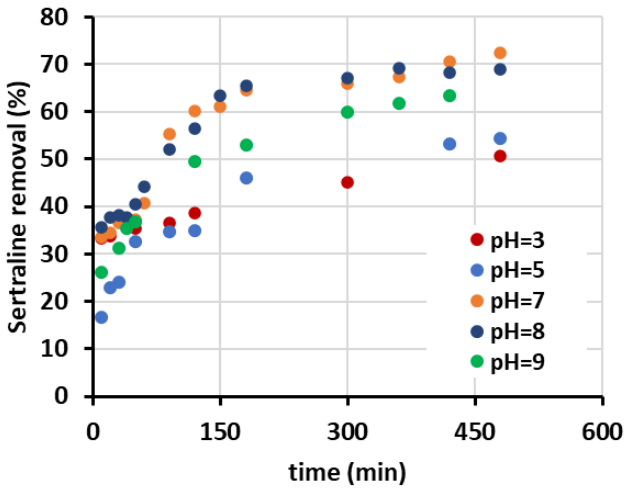

Figure 9 - Effect of pH on the adsorption of sertraline (C = 20 mg/L V= 50 mL, T= 25 ± 2°C, $m_{adsorbent}$ = 25 mg).

In the investigation by Ouasfi *et al.*, 2019, into the removal of aspirin and ketoprofen, a pH_{PZC} value of 6.7 was measured using an olive stone activated carbon adsorbent. Accordingly, at pH values below 6.7 and above 6.7, respectively, the surface of AC is positively charged. The pH of medicinal solutions (150 mg/L) was 3.2 at the beginning. At pH 3.4, aspirin uptake was reported to be 95% higher than it was at pH 12.0, when it was 10.84. At pH 3.4 and pH 12,

respectively, substantial levels of ketoprofen elimination (92%) and 27.16% were noted. The molecules of aspirin and ketoprofen are in their neutral states during the adsorption at pH 3. They are not attracted to the surface's positive charge and can form strong H-bonds with the adsorbent's oxygen-containing surface functional groups.

6.2.2 Effect of adsorbent dosage

The effect of ACOS dosage on sertraline removal was studied by varying the amount of the adsorbent from 10 mg to 55 mg while keeping the other parameters (contact time, pH, initial concentration, and agitation speed) constant. The results are shown in Figure 10 that by increasing the adsorbent dose the adsorption efficiency increased and the number of available adsorption sites increased by increasing the adsorption dose, resulting in the increase of removal efficiency.

Numerous researchers have noted the same behavior. For instance, Reza *et al*. (2014) investigated at the impact of bamboo waste AC dose on the effectiveness of ibuprofen (IBP) removal. The effect of different adsorbent dosages on the adsorption of IBP was studied using different adsorbent dosages that ranged from 10 to 50 mg/20 mL at 298 K temperature and a fixed adsorbate concentration (100 mg/L). With an increase in adsorbent dose from 10 to 40 mg/L, it has been seen that the percentage of IBP elimination improves from 73.45% to 97.00%. The removal efficiency is slightly affected when AC continues to rise (Ruhul *et al*., 2014).

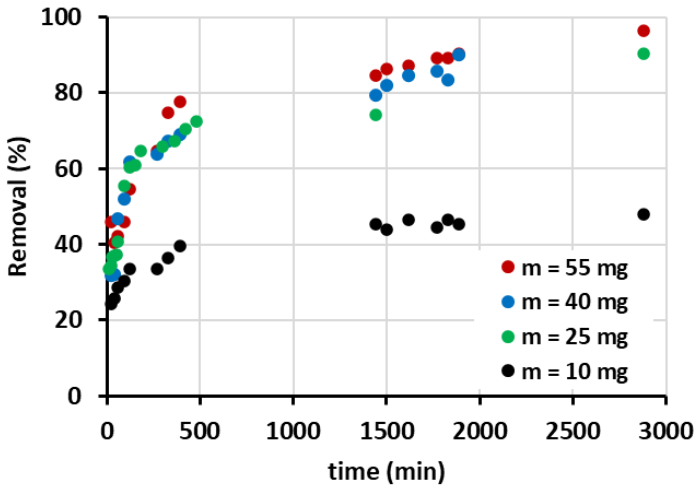

Figure 10 - Effect of adsorbent dosage on the removal of sertraline (C = 20 mg/L V = 50 mL, T = 25 ± 2°C, pH = 7).

6.3. Kinetic study

Kinetics is an important consideration in assessing the adsorption potential of adsorbent. The effect of contact time on the sertraline adsorption capacity of the activated carbon was previously presented in Figure 8. The pseudo-second order model is given in Equation (2) , where k_2 is the pseudo-second order rate constant, and qt is the amount of sertraline adsorbed at time t (min), which was calculated from the slope and intercept of the plot t/qt versus t. Based on the coefficient of determination presented in Table 10. The pseudo-first order and pseudo-second order reaction models were used to study the adsorption kinetics of sertraline dye onto the activated carbon. Only the pseudo-second order model showed an excellent fit to the adsorption data (Figure 11 and Figure 12), which indicated that chemisorption is the rate limiting step. The experimental and calculated adsorption capacities are very close, confirming the application and validation of this model in the description of adsorption data (Table 11).

The results from each of the adsorption kinetics were statistically analyzed, based on these parameters, the model that best described the results of each experiment was determined out of the two evaluated kinetics (pseudo-first order and pseudo-second order).

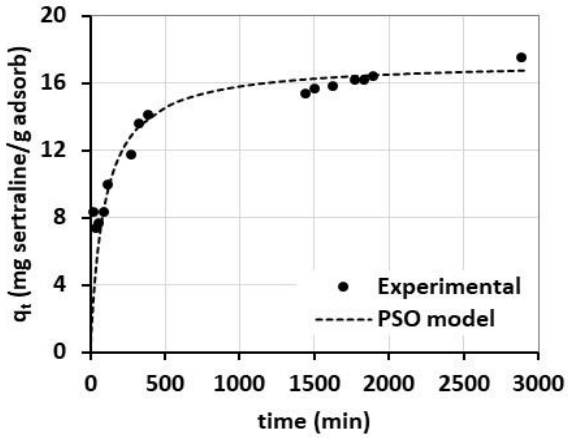

Figure 11 – Kinetics study (non-linear equation): experimental results (points) and fitting of the pseudo-second order model (dashed line). Mass of adsorbent = 55 mg.

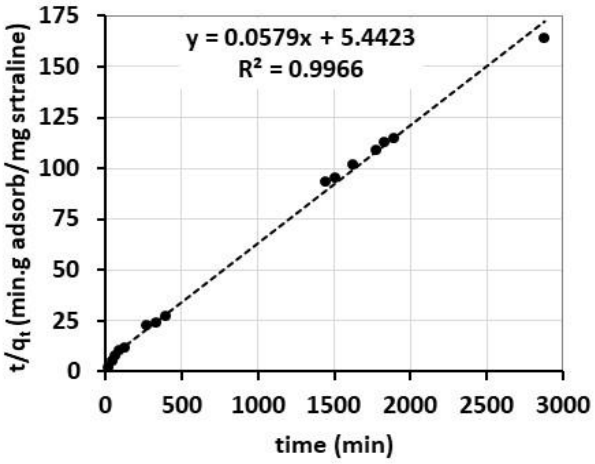

Figure 12 - Kinetics study (linear equation): experimental results (points) and fitting of the pseudo-second order model (dashed line). Mass of adsorbent = 55 mg

Table 70 - Coefficients of the kinetics pseudo-first order and pseudo-second order.

Model	Parameter	Mass of adsorbent (mg)			
		10	**25**	**40**	**55**
PFO	**k_1**	0.0012	0.0049	0.001	**0.0009**
	q_e (mg/g)	48.50	30.00	23.50	**18.10**
	R^2	0.9481	0.9326	0.8937	**0.9474**
PSO	**k_2**	0.00031	0.0009	0.00053	**0.00062**
	q_e (mg/g)	47.85	30.4	23.5	**17.27**
	R^2	0.9981	0.9991	0.9965	**0.9966**

7. Conclusions and suggestions for future work

In the current study, the adsorption potential of the olive stone activated carbon was assessed against sertraline in the temperature of 25 °C. The characteristic parameters and mechanisms of adsorption of the present application were also investigated using isotherms and kinetic models. The optimized conditions for Sertraline removal by the activated carbon were found: pH = 7, agitation rate = 150 rpm, equilibration time = 1440 min, Sertraline concentration = 20 $mg \cdot L^{-1}$ and 55 mg of adsorbent dosage. The adsorption kinetics of sertraline dye onto activated carbon were investigated using the pseudo-first order and pseudo-second order reaction models. The adsorption data was only well-fitted by the pseudo-second order model, suggesting that chemisorption is the rate-limiting step. The experimental and calculated adsorption capacities are very close, validating the implementation and approval of this model in the adsorption data description.

As suggestions for future works, it is suggested that more adsorption equilibrium studies will be carried out with different types of adsorbents such as granulated or none carbonized olive stone. Also, more work will be focused on adsorption isotherm. Other operating conditions can also be studied as lower temperatures, which by an incubator limit could not be performed, and studies of more acidic pHs.

In Tunisia there is an abundance of orange which opens up a variety of possibilities for the application of this plant, that can also be investigated as activated charcoal prepared from orange peel in accordance with this technique and assess the removal of other pharmaceuticals under the same investigational conditions. In addition, the region around Bragança has a large abundance of chestnut trees, which suggests a possible study that could continue this work's line of research.

References

A.O. Adeniji, A.I. Okoh, O.O. Okoh. Distribution and Chemical Analysis of Pharmaceuticals and Personal Care Products (PPCPs) in the Environmental Systems: A Review. Int. J. Environ. Res. Public Health 16(17) (2019) 3026.

Ahmed, M; Theydan, S. (2012) "Adsorption of cephalexin onto activated carbons from Albizia lebbeck seed pods by microwave-induced KOH and K2CO3 activations", Chemical Engineering Journal, 211-212, pp.200-207.

Alleoni, L., Camargo, O. A., & Casagrande, J. Isotermas de Langmuir e de Freundlich na descrição da adsorção de boro em solos altamente intemperizados. Scientia Agricola, 55(3), (1998) 379-387.

Almarsson Ö, Hickey M., Peterson M., Morissette S., Soukasene S., McNulty C., Tawa M., MacPhee J., Remenar J. High-throughput surveys of crystal form diversity of Highly Polymorphic Pharmaceutical Compounds. Crystal Growth and Design (3)6 (2003) 927-933.

Alslaibi, Ismail Abustan, Mohd Azmier Ahmad, Ahmad Abu Foul. Preparation of Activated Carbon From Olive Stone Waste: Optimization Study on the Removal of Cu,Cd, Ni, Pb, Fe, and Zn from Aqueous Solution Using Response Surface Methodology. Journal of Dispersion Science and Technology 35 (2014) 913-925.

Américo J., Isique W., Minillo A., Carvalho L., Torres Nádia. Fármacos em uma Estação de tratamento de efluentes na Região Centro-Oeste do Brasil e os Riscos aos Recursos Hídricos. Brazilian Journal of Water Resources 17(3) (2012) 61-67.

Amin, M. T., Alazba, A. A., & Manzoor, U. A review on removal of pollutants from water / wastewater using different types of nanomaterials. Advances in Materials Science and Engineering 24, (2014) 825910.

Amit Bhatnagar, Kushani Mahatantila, Chamila Jayasinghe, Yong Sik Ok, Meththika Vithanage. Engineered tea-waste biochar for the removal of caffeine, a model compound in pharmaceuticals and personal care products (PPCPs), from aqueous media. Environmental Technology & Innovation 19 (2020) 100847.

Ana Rita Ribeiro, Maria Elizabeth Tiritan. Priority substances and emerging Organic Pollutants in Portuguese Aquatic Environment: A Review. In P. d. Voogt, ed., Reviews of Environmental Contamination and Toxicology. Switzerland: Springer International Publishing, 2016, 1-44.

Andersson, S., Preparative chiral chromatography - a powerful and efficient tool in drug discovery, in Chiral Separation Techniques, Subramanian, G., Editor. Wiley VCH: Weinheim, Germany, (2007) p. 585.

Baccar, R.; Sarrà, M.; Bouzid, J.; Feki, M.; Blánquez, P. Removal of pharmaceutical compounds by activated carbon prepared from agricultural by-product. Chem. Eng. J. 211-212 (2012) 310-317.

Bakir A., Rowland S., Thompson R. Transport of persistent organic pollutants by microplastics in estuarine conditions. Estuarine, Coastal and Shelf Science 140 (2014) 14-21.

Barceló D., Gonzalez S., Petrovic M. Analysis and removal of emerging contaminants in wastewater and drinking water. TrAC Trends in Analytical Chemistry 22(10) (2003) 685-696.

Bard, C., & Cann, M. (2011). Química Ambiental (4ª ed.). (V. d. Amaral, Ed.) Porto Alegre: Bookman.

Beck D., Koenig H., Beck J. Depression. Clinics in Geriatric Medicine (14)4 (1998) 765-786.

Beretta M., Britto V., Tavares T., da Silva S., Pletsch A., 2014. Occurrence of pharmaceutical and personal care products (PPCPs) in marine sediments in the Todos os Santos Bay and the north coast of Salvador, Bahia. Brazilian Journal of Soils and Sediments 14 (2014) 1278-1286.

Bila D., Dezotti M. Desreguladores endócrinos no meio ambiente: efeitos e consequências. Química Nova 30(3) (2007) 651-666.

Birkholz D., Stilson S., Elliott H. Analysis of emerging contaminants in drinking water. Comprehensive Water Quality and Purification 2 (2014) 212-229.

Boelee, E., Geerling, G., Zaan, B. v., Blauw, A., & Vethaak, A. Water and health: From environmental pressures to integrated. Acta Tropica 193 (2019) 217-226.

Bohn, H., McNeal, B., & O'Connor, G. Soil chemistry, 329 (1979).

Boxall A., Rudd M., Brooks B., Caldwell D., Choi K., Hickmann S., Kraak G. Pharmaceuticals and Personal Care Products in the environment: what are the big questions? Environmental Health Perspective 120(9) (2012) 1221-1229.

Braga, B., Hespanhol, I., Conejo, J. G., Mierzwa, J. C., Barros, M. T., Spencer, M., Eiger, S. (2005). Introdução a Engenharia Ambiental (2° ed.). São Paulo: Pearson.

C. Delerue-Matos, L. Santos. Application of experimental design methodology to optimize antibiotics removal by walnut shell based activated carbon. Science of the Total Environment 646 (2019) 168-176.

Campanha M., Awan A., Sousa D., Grosseli G., Mozeto A., Fadini P. A 3- year study on occurrence of emerging contaminants in an urban stream of São Paulo State of Southeast Brazil. Environmental Science and Pollution Research 22(10) (2015) 7936-7947.

Carla V. Gómez-Pacheco, Manuel Sánchez-Polo, Jesús J. López-Peñalver, RaúlOcampo-Pérez. Tetracycline removal from water by 65 adsorption/bioadsorption on activated carbons and sludge-derived adsorbents. Journal of Environmental Management 131, (2013) 16-24.

Chapman, P.M. Emergent substances: emerging problems? Environmental Toxicology and Chemistry 25(6) (2006) 1445-1447.

Choubert J., Martin S., Esperanza M., Budzinski H., Miege C., Lagarrigue C., Coquery M. Removal of Micropollutants from Secondary Effluents and Sludge by Various Processes in Rural and Peri-urban Areas, Treatment Technical, Environmental & Economic Challenges, Jun 2014, Verona, Italy. 5 p. hal-01058679.

Ciola, R. Fundamentos da cromatografia a líquido de alto desempenho. Editora Edgard Blücher, 1ªEds. São Paulo, Brasil, 1998.

Coelho G., Gonçalves A., Sousa R., Schwantes D., Miola A., Domingues C. Uso de técnicas de adsorção utilizando resíduos agroindustriais na remoção de contaminantes em águas. Journal of Agronomic Sciences 3 (2014) 291-317.

Cohen Z. e Derubeis R. Treatment selection in depression. Annual Review of Clinical Psychology 14 (2018) 209-236. Decisão de Execução (UE) 2018/840 da Comissão de 5 de junho de 2018.

Commission Implementing Decision (EU) 2015/495 Of 20 March 2015 Establishing a Watch List of Substances for Union-wide Monitoring in the Field of Water Policy Pursuant to Directive 2008/105/EC of the European Parliament and of the Council (notified Under Document C, 2015).

Commission Implementing Decision (EU) 2018/840 of 5 June 2018 establishing a watch list of substances for Union-wide monitoring in the field of water policy pursuant to Directive

2008/105/EC of the European Parliament and of the Council and repealing Commission Implementing Decision (EU) 2015/495.

Costa Junior I., Pletsch A., Torres Y. Ocorrência de fármacos antidepressivos no meio ambiente-revisão. Revista Virtual de Química 6(5) (2014) 1408-1431.

Cruz, J. V., Fontiela, J., Prada, S., & Andrade, C. The chemical status of groundwater and pollution risk in the Azores archipelago (Portugal). Environmental Earth Sciences 73 (2015) 2763-2777.

Directive 2013/39/EU of the European Parliament and of the Council of 12 August 2013 amending Directives 2000/60/EC and 2008/105/EC as regards priority substances in the field of water policy.

Dolan J., A guide to HPLC and LC-MS Buffer Selection, ACE HPLC Columns, Scotland. Disponível em: http://www.ace-hplc.com. DrugBank online (acesso em 2021). https://go.drugbank.com/drugs/DB01104.

Eline Boelee, Gertjan Geerling, Bas van der Zaan, Anouk Blauw, A. Dick Vethaak."Water and health: From environmental pressures to integrated responses. Acta Tropica 193 , 2019, 217–226.

Esteves, O. A tradução e a sua relevância na indústria farmacêutica. Dissertação, Grau de Mestre em Tradução Especializada, Universidade de Aveiro, 2015.

Farias M. e Carneiro R. Simultaneous Quantification of three polymorphic forms of carbamazepine using Raman Spectroscopy and Multivariate Calibration. Analytical Letters 47 (2014) 1043-1051.

Farias M., Soares F., Carneiro R. Crystalline phase transition of ezetimibe in final product, after packing, promoted by the humidity of excipients: Monitoring and quantification by Raman spectroscopy. Journal of Pharmaceutical and Biomedical Analysis 121 (2016) 209-214.

Fent K., Weston A., Caminada D. Ecotoxicology of human pharmaceuticals. Aquatic Toxicology 76 (2006) 122-159.

Filho R., Barreiro J., Vieira, E., Cass Q. Fármacos, ETEs e corpos hídricos. Revista Ambiente e Água (2)3 (2007) 54-61.

Garric J., Ferrari B. Les substances pharmaceutiques dans les milieux aquatiques. Niveaux d'exposition et effets biologique: que savons-nous? Revue des Sciences de l'eau 18 (2005) 307-330.

Garrison A., Pope J., Allen F. Identification and Analysis of Organic Pollutants in Water; Keith C.; Ed.; Ann Arbor Science Publishers: Ann Arbor, 1976.

Gavrilescu M., Demnerová K., Aamand J., Agathos S., Fava F. Emerging pollutants in the environment: present and future challenges in biomonitoring, ecological risks and bioremediation. New Biotechnology 32(1) (2015) 147-156.

George Z. Kyzas, Eleni A. Deliyanni, Modified activated carbons from potato peels as green environmental-friendly adsorbents for the treatment of pharmaceutical effluents. Chemical Engineering Research and Design 97 (2015) 135-144.

Gertjan Geerling, Bas van der Zaan, Anouk Blauw, A. Dick Vethaak. Water and health: From environmental pressures to integrated responses. Acta Tropica 193 (2019) 217-226.

Ghadir Nazari, Hossein Abolghasemi, Mohammad Esmaieli, Adel Hosseini, Mohammad Foroughi-dahr, Adsorption Isotherm of Cephalexin Antibiotic Using Modified Walnut Shell, The 8th International Chemical Engineering Congress & Exhibition (IChEC 2014) Kish, Iran, 2014, 24-27.

Ghiselli G. Avaliação da qualidade das águas destinadas ao abastecimento público na região de Campinas: ocorrência e determinação dos interferentes endócrinos (IE) e produtos farmacêuticos e de higiene pessoal (PFHP). Tese de Doutorado, Universidade Estadual de Campinas, Brasil, 2001.

Giger W. Hydrophilic and amphiphilic water pollutants using advanced analytical methods for classic and emerging contaminants. Analytical and Bioanalytical Chemistry 393 (2009) 37-44.

Golovko O., Kumar V., Fedorova G., Randak T., Grabic R. Seasonal changes in antibiotics, antidepressants/psychiatric drugs, antihistamines and lipid regulators in a wastewater treatment plant. Chemosphere 111 (2014) 418-426.

Grabicova K., Grabic R., Fedorova G., Fick J., Cerveny D., Kolarova J., Turek J., Zlabek V., Randak T. Bioaccumulation of psychoactive pharmaceuticals in fish in an effluent dominated stream. Water Research 124 (2017) 654-662.

Halling-Sørensen B., Nielsen S., Lanzky P., Ingerslev F., Lutzhoft H., Jorgensen S. Occurrence, fate and effects of pharmaceutical substances in the environment – a review. Chemosphere 36 (1998) 357-394.

Hayet Mansouri, Rocio J. Carmona, Alicia Gomis-Berenguer, Souad SouissiNajar, Abdelmottaleb Ouederni, Conchi O. Ania, "Competitive adsorption of ibuprofen and amoxicillin mixtures from aqueous solution on activated carbons", Journal of Colloid and Interface Science 449, 2015, 252–260.

Hignite C. and Azarnoff D. Drugs and drug metabolites as an environmental sewage water effluent. Life Sciences 20(2) (1977) 337-341.

Husein, D.Z.; Hassanien, R.; Al-Hakkani, M.F. Green-synthesized copper nano-adsorbent for the removal of pharmaceutical pollutants from real wastewater samples. Heliyon 5 (2019) e02339.

I. Yahiaoui, S. Saidi, K. Yahiaoui, L. Kaabache, M. Zennache and F. Aissani-Benissad. Adsorption of pharmaceutical residues on adsorbents prepared from olive stones using mixture design of experiments model. Water Science and Technology, 80(5) (2019) 998-1009.

Imen Ghouma, Abdelmottaleb Ouederni, Mejdi Jeguirim. Amoxicillin removal from aqueous solution using activated carbon prepared by chemical activation of olive stone. Environmental Science and Pollution Research 24(11) (2017) 9993-10004.

INFARMED, Prontuário Terapêutico on-line, Portugal, 2021.

Isacsson G. e Rich C. Antidepressant drugs and the risk of suicide in children and adolescents. Pediatric Drugs (16)2 (2014) 115-122.

Istilli P., Miasso A., Padovan C., Crippa J., Tirapelli C. Antidepressivos: uso e conhecimento entre estudantes de enfermagem. Revista Latino-Americana de Enfermagem (18)3 (2010) 131-139.

J. V. Cruz, J. Fontiela, S. Prada, C. Andrade. "The chemical status of groundwater and pollution risk in the Azores archipelago (Portugal)". Environ Earth Sci 73 , 2015, 2763–2777.

Jank L., Hoff R., Costa F., Pizzolato T. Simultaneous determination of eight antibiotics from distinct classes in surface and wastewater samples by solid-phase extraction and high-performance liquid chromatography-electrospray ionization mass spectrometry. International Journal of Environmental Analytical Chemistry 94(10) (2014) 1013-1037.

Jelić A., Gros M., Petrović M., Ginebreda A., Barceló D. Occurrence and elimination of pharmaceuticals during conventional wastewater treatment. In: Guasch H., Ginebreda A., Geiszinger A. (eds) Emerging and Priority Pollutants in Rivers. The Handbook of Environmental Chemistry, vol 19. Springer, Berlin, Heidelberg, 2012.

Jiang J., Zhou Z., Sharma V. K. Occurrence, transportation, monitoring and treatment of emerging micro-pollutants in wastewater - A review from global views. Microchemical Journal 110 (2013) 292-300.

Jodeh, S.; Abdelwahab, F.; Jaradat, N.; Warad, I.; Jodeh, W. Adsorption of diclofenac from aqueous solution using Cyclamen persicum tubers based activated carbon (CTAC). J. Assoc. Arab. Univ. Basic Appl. Sci. 20 (2016) 32-38.

Johnson E. Stevenson R. Basic liquid chromatography. Palo Alto: Varian Associates, 1978.

Jones O., Lester J., Voulvoulis N. Pharmaceuticals: a threat to drinking water? Trends in Biotechnology 23(4) (2005) 163-167.

José Rivera-Utrilla, Carla V. Gómez-Pacheco, Manuel Sánchez-Polo, Jesús J. López-Peñalver, RaúlOcampo-Pérez, "Tetracycline removal from water by adsorption/bioadsorption on activated carbons and sludge-derived adsorbents", Journal of Environmental Management 131, 2013, 16-24.

Khatereh Salari, Zahra Atashi Yazdi. Preparation of activated carbon from agricultural wastes (almond shell and orange peel) for adsorption of 2-pic from aqueous solution. Journal of Industrial and Engineering Chemistry 20 (2014) 1892-1900.

Khetan S. e Collins T. Human pharmaceuticals in the aquatic environment: A challenge to green chemistry. Chemistry Reviews (107)6 (2007) 2319-2364.

Kovo G. Akpomie, Jeanet Conradie, Department of Chemistry, University of the Free State, Bloemfontein, South Africa, 2021.

Krzeminski, Pawel; Tomei, Maria Concetta; Karaolia, Popi; Langenhoff, Alette; Almeida, C. Marisa R.; Felis, Ewa; Gritten, Fanny; Andersen, Henrik Rasmus; Fernandez, Telma; Manaia, Celia. Performance of secondary wastewater treatment methods for the removal of contaminants of emerging 63 concern implicated in crop uptake and antibiotic resistance spread: A review. Science of The Total Environment 648 (2019) 1052-1081.

Kümmerer K. The presence of pharmaceuticals in the environment due to human use – present knowledge and future challenges. Journal of Environmental Management 90(8) (2009) 2354-2366.

Kuzmanovic M., Lopez-Doval J, de Castro-Catala N., Guasch H., Petrovic M., Muñoz I., Ginebreda A., Barcelo D. Ecotoxicological risk assessment of chemical pollution in four iberian river basins and its relationship with the aquatic macroinvertebrate community status. Science of the Total Environment 540 (2016) 324-333.

L. Nielson, P. Zhang, T. J. Bandosz, "Adsorption of carbamazepine on sludge/fish waste derived adsorbents: Effect of surface chemistry and texture", Chemical Engineering Journal, 267, 2015, 170–181.

Lajeunesse A., Smyth S., Barclay K., Sauve S., Gagnon C. Distribution of antidepressant residues in wastewater and biosolids following different treatment processes by municipal wastewater treatment plants in Canada. Water Research 46 (2012) 5600-5612.

Listunova L., Roth C., Bartolovic M., Kienzle J., Bach C., Weisbrod M., Roesh-Ely D. Cognitive impairment along the course of depression: non pharmacological treatment options. Psychopathology (51)5 (2018) 295-305.

Lolić A., Paíga P., Santos L., Ramos S., Correia M., Delerue-Matos C. Assessment of non-steroidal anti-inflammatory and analgesic pharmaceuticals in seawaters of North of Portugal: Occurrence and environmental risk. Science of The Total Environment 508 (2015) 240-250.

Lopes V., Rienne R., da Silva A., Torquilho D., Carreira R., Marques M. Development of a solid-phase extraction system modified for preconcentration of emerging contaminants in large sample volumes from rivers of the lagoon system in the city of Rio de Janeiro, Brazil. Marine Pollution Bulletin 110(1) (2016) 572-577.

Lotfi A, Manzoori JL, Mohagheghi A. Determination of sertraline in pharmaceutical and biological samples using 1, 10-phenanthroline-terbium probe and silver nanoparticles enhanced fluorescence. J. Luminescence 185 (2017) 132-140.

Lough W. e Wainer I. (Eds.). High performance liquid chromatography: fundamental principles and practice. London: Blackie Academic & Professional, 1996.

Luo Y., Guo W., Ngo H., Nghiem L., Hai F., Zhang J., Liang S., Wang X. A review on the occurrence of micropollutants in the aquatic environment and their fate and removal during wastewater treatment. Science of the Total Environment 473 (2014) 619-641.

M. Ahmaruzzaman, Asim K. Sil, Vinod Kumar Gupta. Comparative Adsorption Behavior of Ibuprofen and Clofibric Acid onto Microwave Assisted Activated Bamboo Waste. Ind. Eng. Chem. Res. 53 (2014) 9331-9339.

M. Sarra, J. Bouzid, M. Feki, P. Blanquez. Removal of pharmaceutical compounds by activated carbon prepared from agricultural byproducts. Chemical Engineering Journal, 211–212 (2012) 310–317.

M. Zbair S. Bouzikri, Z. Anfar, M. Bensitel, H. Ait Ahsaine, E. Sabbard and L. Khamliche, Selected pharmaceuticals removal using algae derived porous carbon: experimental, modelling and DFT theoretical insights, RSC Adv. 9 (2019) 9792-9808.

Machado K., Grassi M., Vidal C., Pescara I., Jardim W., Fernandes A., Sodré F., Almeida F., Santana J., Canela M, Nunes C., Bichinho K., Severo F. A preliminary nationwide survey of the presence of emerging contaminants in drinking and source waters in Brazil. Science of the Total Environment 572 (2016) 138-146.

Machado, M. Deteção de antidepressivos em águas superficiais e residuais. Tese de Dissertação e Mestrado em Química Medicinal, Universidade do Minho, Portugal, 2013.

Madureira T., Barreiro J., Rocha M., Rocha E., Cass Q., Tiritan M. Spatiotemporal distribution of pharmaceuticals in the Douro River estuary (Portugal). Science of the Total Environment 408 (2010) 5513-5520.

Manvendra Patel, Rahul Kumar, Kamal Kishor, Todd Mlsna, Charles U. Pittman, Jr., Dinesh Mohan. “Pharmaceuticals of Emerging Concern in Aquatic Systems: Chemistry, Occurrence, Effects, and Removal Methods”. Chemical Reviews, 2019, 3510–3973.

Marsik P., Rezek J., Zidkova M., Kramulova B., Tauchen J., Vanek T. Nonsteroidal anti-inflammatory drugs in the watercourses of Elbe basin in Czech Republic. Chemosphere 171 (2017) 97-105.

Marzbali, Mohamad Esmaieli, Hossein Abolghasemi, MostafaHedayati Marzbali, Tetracycline adsorption by H3PO4-activated carbon produced from apricot nut shells: A batch study. Process Safety and Environmental Protection 102 (2016) 700-709.

Matos S. Operações unitárias: fundamentos, transformações e aplicações dos fenômenos físicos e químicos. Editora Érica (1ª edição) São Paulo, Brasil, 2015.

Metcalf L. and Harrison E. Tratamento de efluentes e recuperação de recursos. AMGH, 5th Edition. Porto Alegre, Brasil, 2017.

Miller J., Miller R. Statistics and Chemometrics for Analytical Chemistry. Pearson Education Limited (Vol. 7th Edition), 2018.

Minten, J., Adolfsson-Erici, M., Alsberg, T. Extraction and analysis of pharmaceuticals in polluted sediment using liquid chromatography mass spectrometry. International Journal of Environmental Analytical Chemistry, 91(6) (2011) 553-566.

Mole A., Brooks, B. Global scanning of selective serotonin reuptake inhibitors: occurrence, wastewater treatment and hazards in aquatic systems. Environmental Pollution 250 (2019) 1019-1031.

Mondal, S.; Patel, S.; Majumder, S.K. Bio-extract assisted in-situ green synthesis of Ag-RGO nanocomposite film for enhanced naproxen removal. Korean J. Chem. Eng. 37 (2020) 274-289.

Moreno R., Moreno D., Soares M. Psicofarmacologia de antidepressivos. Revista Brasileira de Psiquiatria (21)1 (1999) 24-40.

Mostafalou, S. Persistent Organic Pollutants and Concern Over the Link with Insulin Resistance Related Metabolic Diseases. In P. d. Voogt, ed., Reviews of Environmental Contamination and Toxicology. Switzerland: Springer International Publishing, 2016, 66-69.

Nascimento R., Lima A., Vidal C., Melo D., Giselle S. Adsorção: aspetos teóricos e aplicações ambientais. Fortaleza: Imprensa Universitária da Universidade Federal do Ceará, Fortaleza, Brasil, 2014.

Nebot C., Gibb S., Boyd K. Quantification of human pharmaceuticals in water samples by high performance liquid chromatography-tandem mass spectrometry. Analytica Chimica Acta 598 (2007) 87-94.

Nikolaou A., Meric S., Fatta D. Occurrence patterns of pharmaceuticals in water and wastewater environments. Analytical and Bioanalytical Chemistry 387 (2007) 1225-1234.

Ninwiwek N, Hongsawat P, Punyapalakul P, Prarat P, Removal of the antibiotic sulfamethoxazole from environmental water by mesoporous silicamagnetic graphene oxide

nanocomposite technology: Adsorption characteristics, coadsorption and uptake mechanism. Colloids and Surfaces A: Physicochemical and Engineering Aspect 580 (2019) 123716.

Ortiz de García S., Pinto G., García P., Mata R. Consumption and occurrence of pharmaceutical and personal care products in the aquatic environment in Spain. Science of The Total Environment 444 (2013) 451-465.

Osorio V., Larrañaga A., Aceña J., Perez S., Barcelo D. Concentration and risk of pharmaceuticals in freshwater systems are related to the population density and the livestock units in Iberian Rivers. Science of The Total Environment 540 (2016) 267-277.

P. Zhang, T. J. Bandosz. Adsorption of carbamazepine on sludge/fish waste derived adsorbents: Effect of surface chemistry and texture. Chemical Engineering Journal 267 (2015) 170-181.

Paíga P., Correia M., Fernandes M., Silva A., Carvalho M., Vieira J., Jorge S., Silva J., Freire C., Delerue-Matos, C. Assessment of 83 pharmaceuticals in WWTP influent and effluent samples by UHPLC-MS/MS: Hourly variation. Science of The Total Environment 648 (2019) 582-600.

Pal A., Gin K.Y.-H., Lin A.Y.-C., Reinhard M. Impacts of emerging organic contaminants on freshwater resources: review of recent occurrences, sources, fate and effects. Science of the Total Environment 408 (2010) 6062-9.

Pal A., He Y., Jekel M., Reinhard M., Gin K. Emerging contaminants of public health significance as water quality indicator compounds in the urban water cycle. Untreated water Sewer system. Environment International 71 (2014) 46-62.

Parker DS. Introduction of new process technology into the wastewater treatment sector. Water Environment Research 83 (2011) 483-97.

Petrovic M., Hernando M., Díaz-Cruz M., Barceló D. Liquid chromatographytandem mass spectrometry for the analysis of pharmaceutical residues in environmental samples: a review. Journal of Chromatography A 1067(1-2) (2005) 1-14.

Pratibha R. Gawande, Dr.Jayant P. Kaware. Preparation and activation of activated carbon from waste materials – A review. International Journal for Research in Applied Science & Engineering Technology 4(XII) (2016) 2321-9653.

Rahul Kumar, Kamal Kishor, Todd Mlsna, Charles U. Pittman, Jr., Dinesh Mohan. Pharmaceuticals of Emerging Concern in Aquatic Systems: Chemistry, Occurrence, Effects, and Removal Methods. Chemical Reviews (2019) 3510-3973.

Reis Filho R., Barreiro J., Vieira E., Cass Q. Fármacos, ETEs e corpos hídricos. Revista Ambiente & Água 2(3) (2007) 54-61.

Reis-Santos P., Pais M., Duarte B., Caçador I., Freitas A., Vila Pouca A., Barbosa J., Leston S., Rosa J., Ramos F., Cabral H., Gillanders B., Fonseca V. Screening of human and veterinary pharmaceuticals in estuarine waters: a baseline assessment for the Tejo estuary. Marine Pollution Bulletin 135 (2018) 1079-1084.

Rocio J. Carmona, Alicia Gomis-Berenguer, Souad SouissiNajar, Abdelmottaleb Ouederni, Conchi O. Ania, Competitive adsorption of ibuprofen and amoxicillin mixtures from aqueous solution on activated carbons. Journal of Colloid and Interface Science 449 (2015) 252-260.

Rowsell V., Tangney P., Hunt C., Voulvoulis N. Estimating levels of micropollutants in municipal wastewater. Water, Air, Soil Pollution 206 (2010) 357-368.

Ruhul Amin Reza, M. Ahmaruzzaman, Asim K. Sil, Vinod Kumar Gupta, "Comparative Adsorption Behavior of Ibuprofen and Clofibric Acid onto Microwave Assisted Activated Bamboo Waste", Ind. Eng. Chem. Res. 53, 2014, 9331 – 9339.

S. Dube, M.M. Nindi. Removal of non-steroidal antiinflammatory drugs (NSAIDs) and carbamazepine from wastewater using water-soluble protein extracted from Moringa stenopetala seeds. Journal of Environmental Chemical Engineering 6 (2018) 3095-3103.

S. Rodrigues, N. Lapa, I. Matos, F. Lemos, M. K. S. Batista, A. P. Carvalho, I. Fonseca High efficacy on diclofenac removal by activated carbon produced from potato peel waste, International Journal of Environmental Science and Technology 13 (2016) 1989-2000.

Saeedeh Hashemian, Khatereh Salari, Zahra Atashi Yazdi, "Preparation of activated carbon from agricultural wastes (almond shell and orange peel) for adsorption of 2-pic from aqueous solution", Journal of Industrial and Engineering Chemistry 20, 2014, 1892–1900.

Sakari M., Hsia B., Tahir R., Rafiq S., Nahavandi R., Shah M., Annammala K., Soon Z., Yi A. Estuary and sea - associated wetlands as final sink for organic pollutants: a case study in Sabah, Malaysia. International Journal of Environmental and Bioenergy 9 (2014) 1-16.

Santos L., Araújo A., Fachini A., Pena A., Delerue-Matos C, Montenegro M. Ecotoxicological aspects related to the presence of pharmaceuticals in the aquatic environment. Journal of Hazardous Materials (175)1-3 (2010) 45-95.

Schlüsener M., Hardenbicker P., Nilson E., Schulz M., Viergutz C., Ternes T. Occurrence of venlafaxine, other antidepressants and selected metabolites in the Rhine catchment in the face of climate change. Environmental Pollution 196 (2015) 247-256.

Scott Peacor, Katharina Grosser, Lisette N. De Senerpont Domis, and Miquel Lurling. Pharmaceuticals May Disrupt Natural Chemical Information Flows and Species Interactions in Aquatic Systems: Ideas and Perspectives on a Hidden Global Change. In P.d. Voogt, ed., Reviews of 61 Environmental Contamination and Toxicology. Switzerland: Springer International Publishing, 2016, 91-106.

Shizong Wang. Removal of pharmaceuticals and personal care products (PPCPs) from wastewater: Review. Journal of Environmental Management 182 (2016) 620-640.

Silva C. and Collins C. Aplicações de cromatografia líquida de alta eficiência para o estudo de poluentes orgânicos emergentes. Química Nova 34(4) (2011) 665-676.

Silva L., Meisel L., Lino C., Pena A., 2014. Profiling serotonin re-uptake inhibitors (SSRIs) in the environment: trends in analytical methodologies. Critical Reviews in Analytical Chemistry 44 (2014) 41-67.

Silva S. Padronização e validação do método extração sortiva em barra de agitação e cromatografia líquida de alta eficiência (SBSE/HPLC) para a determinação de antidepressivos em amostras de plasma. Dissertação de Mestrado em Toxicologia, Universidade de São Paulo, Brasil, 2007.

Soares A., Leão M., Contaminação dos mananciais por micropoluentes e a precária remoção desses contaminantes nos tratamentos convencionais para água potável. Revista Jurídica De Júri (14)4 (2015) 36-85.

Sodré F., Montagner M., Jardim W. Ocorrência de interferentes endócrinos e produtos farmacêuticos em águas superficiais da região de Campinas (SP, Brasil). Journal of the Brazilian Society of Ecotoxicology 2(2) (2007) 187-196.

Solla S., Gilroy E., Klinck J., King L., McInnis R., Struger J., Backus S., Gillis P. Bioaccumulation of pharmaceuticals and personal care products in the unionid mussel Lasmigona costata in a river receiving wastewater effluent. Chemosphere 146 (2016) 486-496.

Souza F. Tratamento da depressão. Brazilian Journal of Psychiatry 21 (1999) 18-23.

Stumpf M., Ternes T., Wilken R., Rodrigues S., Baumann W. Polar drug residues in sewage and natural waters in the state of Rio de Janeiro, Brazil. The Science of the Total Environment 225 (1999) 135-141.

Sumona Show, Soumya Banerjee, Gopinath Halder. Mechanistic insight into sorptive elimination of ibuprofen employing bidirectional activated biochar from sugarcane bagasse: Performance evaluation and cost estimation. Journal of Environmental Chemical Engineering 6(4) (2018) 5287-5300.

T.G. Kebede, S. Dube, M.M. Nindi, "Removal of non-steroidal antiinflammatory drugs (NSAIDs) and carbamazepine from wastewater using water-soluble protein extracted from Moringa stenopetala seeds", Journal of Environmental Chemical Engineering, 6, 2018, 3095–3103.

Tambosi, J. Remoção de fármacos e avaliação de seus produtos de degradação através de tecnologias avançadas de tratamento. Dissertação de Mestrado em Engenharia Química, Universidade Federal de Santa Catarina, Brasil, 2008.

Tamer M. Alslaibi, Ismail Abustan, Mohd Azmier Ahmad, Ahmad Abu Foul, "Preparation of Activated Carbon From Olive Stone Waste: Optimization Study on the Removal of Cu,Cd, Ni, Pb, Fe, and Zn from Aqueous Solution Using Response Surface Methodology", Journal of Dispersion Science and Technology, 35, 2014, 913–925.

Thomas K., Silva F., Langford K., Souza A., Nizzeto L., Waichman A. Screening for selected human pharmaceuticals and cocaine in the urban streams of Manaus, Amazonas, Brazil. Journal of the American Water Resources Association 50(2) (2014) 302-308.

Viali, A. d. (2014). Avaliação da eficiência de remoção de hormônios em estações de tratamentos de efluente. Monografia, Universidade Federal de Juiz de Fora, Juiz de Fora.

Wang. A general kinetic model for adsorption: Theoretical analysis and modelling. Journal of Molecular Liquids 288 (2019) 111100.

Wannmacher L. Abordagem da depressão maior em idosos: medidas não medicamentosas e medicamentos. Organização Pan-Americana da Saúde/Organização Mundial da Saúde (OPAS/OMS) no Brasil (1)1, 1-10, 2016.

Webb S., Ternes T., Gilbert M., Olejniczak K. Indirect human exposure to pharmaceuticals via drinking water. Toxicology Letters (142)3 (2003) 157-167.

Zhou M., Foley J. Analytical method for the quantitation of sertraline hydrochloride stereoisomers by electrokinetic chromatography. Journal of Chromatography A 1052(1-2) (2004) 13-23.