Chapter 3 Filtration as gray water treatment using conventional and unconventional adsorbent beds

Capítulo 3 La filtración como tratamiento del agua gris utilizando lechos adsorbentes convencionales y no convencionales

GARCIA-SANCHEZ, José Juan †* & GARCIA-GARCIA, Eduardo

Tecnológico Nacional de México, Tecnológico de Estudios Superiores de Jocotitlán, Carretera Toluca-Atlacomulco Km 44.8, Ejido de San Juan y San Agustín Jocotitlán, 50700 Jocotitlán, México

ID 1st Author: *Jose Juan, García-Sanchez*

ID 1st Co-author: *Eduardo, García-García* / **ORC ID**: 0009-0002-5176-7845

DOI: 10.35429/H.2023.5.29.46

J. García & E. García

*jjuangs1@gmail.com

R. López (AA.) Engineering and Architecture in the Northern part of the State of Mexico. Handbooks-TI-©ECORFAN-Mexico, Estado de México, 2023

Abstract

Water pollution is a global problem that can be a threat to the environment and human health, which is why efficient technologies are required for the treatment and comprehensive management of residues from wastewater treatment. In this sense, the present study used different filtration media such as zeolite, pumicite, tezontle, dolomite, ground corn straw, coconut fiber and biocalcium to analyze the physical-chemical interaction of these materials and the components of graywater from laundry in a simple filtering process. Four filter columns with different bed layers, same graywater and a filtration rate established by each filter were installed and operated at laboratory scale and in parallel. The pollution reduction was from 70.2% - 98% for selected parameters (COD, TSS, TDS, PO_4 and NO_3) in filter columns. Thus, filters with different arrangement of unconventional filtration media are efficient in purifying greywater.

Wastewater, Adsorption, Unconventional adsorbents, Filtration

Resumen

La contaminación del agua es un problema global que puede constituir una amenaza para el medio ambiente y la salud humana, por lo que se requieren tecnologías eficientes para el tratamiento y manejo integral de los residuos del tratamiento de aguas residuales. En este sentido, el presente estudio utilizó diferentes medios de filtración como zeolita, pumicita, tezontle, dolomita, paja de maíz molida, fibra de coco y biocalcio para analizar la interacción físico-química de estos materiales y los componentes de las aguas grises de lavandería en un proceso de filtración simple. Se instalaron y operaron a escala de laboratorio y en paralelo cuatro columnas filtrantes con diferentes capas de lecho, las mismas aguas grises y una tasa de filtración establecida por cada filtro. La reducción de la contaminación fue del 70,2% - 98% para los parámetros seleccionados (DQO, SST, SDT, PO4 y NO3) en las columnas filtrantes. Así pues, los filtros con diferentes disposiciones de medios de filtración no convencionales son eficaces para depurar las aguas grises.

Aguas residuales, Adsorción, Adsorbentes no convencionales, Filtración

1 Introduction

Water is a highly vulnerable resource, so it is necessary to design a water management system from a circular economy perspective; optimizing use and consumption; reducing the amount of energy and chemicals used in treatment systems. The current management in the treatment of residual water is inefficient and contributes to the production of waste and contamination in other environmental vectors. The soil is a vector that has been affected by solid waste from treatment plants, due to its chemical composition and toxicity. The effects of the current models of wastewater treatment on the soil, mainly agricultural, make it necessary to generate technological and management alternatives.

The consumption of washing water is one of the most critical issues, where large amounts of water are used for washing every day (Manouchehri & Kargari, 2017). Laundromat effluents are categorized as graywater and their effluents contain detergents, degreasers, neutralizers, and softeners. Detergents are a source of phosphorus in wastewater, they inhibit biological activity and decrease oxygen solubility. Moreover, dyes contained in graywater persist in the environment, are difficult and expensive to remove. The usual characteristics of these effluents are pH: 7.5 - 11.5, alkalinity: 60 - 250 mg/L of Na_2CO_3, total solids 800 - 1200 mg/L, BOD 30 - 305 mg/L, COD 150 - 2054 mg/L and phosphates 5 – 7 mg/L (Eriksson *et al*., 2002).

Some processes to treat these effluents are through membrane filtration or activated carbon and Advanced Oxidation Processes can be used to reduce dyes (López *et al*., 2007). The filtration process is a treatment that removes; fecal coliforms, suspended, dissolved and total solids, BOD, Oils and Fats.

A filter is made up of a filter medium and a support with several layers of different materials and commonly has a last layer that provides support and aeration to the system, ensuring the permeability of the filter. The filters combine the filtration operation with adsorption, using filter materials that in turn act as adsorbents.

An ideal filtration medium is one, with a certain granulometry and grains of a certain specific weight, which is capable of removing the greatest possible number of suspended particles from an effluent. Hence, the materials of a filtration medium must have a high retention capacity (Molina, 2016). Materials such as zeolite, pumicite, tezontle, dolomite in a filtration process may serve as a support. While ground corn straw, coconut fiber and biocalcium can be used as organic filtration media.

The objective of this research was to analyze the filtration efficiency, the quality of the treated water and the properties of the generated bed to determine the efficiency of water purification. It is intended to find a solution for the integral management of wastewater from laundry.

1.1 Water

Water is one of the most important resources in the world. It constitutes most of living matter and helps in different biological processes, water is the second most essential material for human survival (S. Ahuja, 2009; Elehinafe *et al.*, 2022). It is also fundamentally important for human activity, it is needed and used for practically everything, from household domestic use to industrial and agricultural production (Oki & Quiocho, 2020).

Around 70% of the Earth is covered by water, of which 97% of this is sea water (S. Ahuja, 2009; Grzegorzek *et al.*, 2023). Since seawater is rarely available for human consumption, the world population depends on only the 3% available freshwater. Out of the available freshwater, only 0.06% can be easily accessed as the rest comprises the frozen polar ice cap or glaciers, groundwater, and swam (Musie & Gonfa, 2023).

Due to the relevance of this resource and as the world’s population increases, the demand for water is growing day by day and threatens to exacerbate water scarcity in many areas (Qu *et al.*, 2013). Additionally, climate change affects water scarcity by altering both water supply and demand (Sun *et al.*, 2023). The spatial and temporal distribution of water resources are affected by climate change, and the use of water in irrigation and other sectors (energy and food production) is also affected by changes in temperature (Orlowsky *et al.*, 2014; Sun *et al.*, 2023).

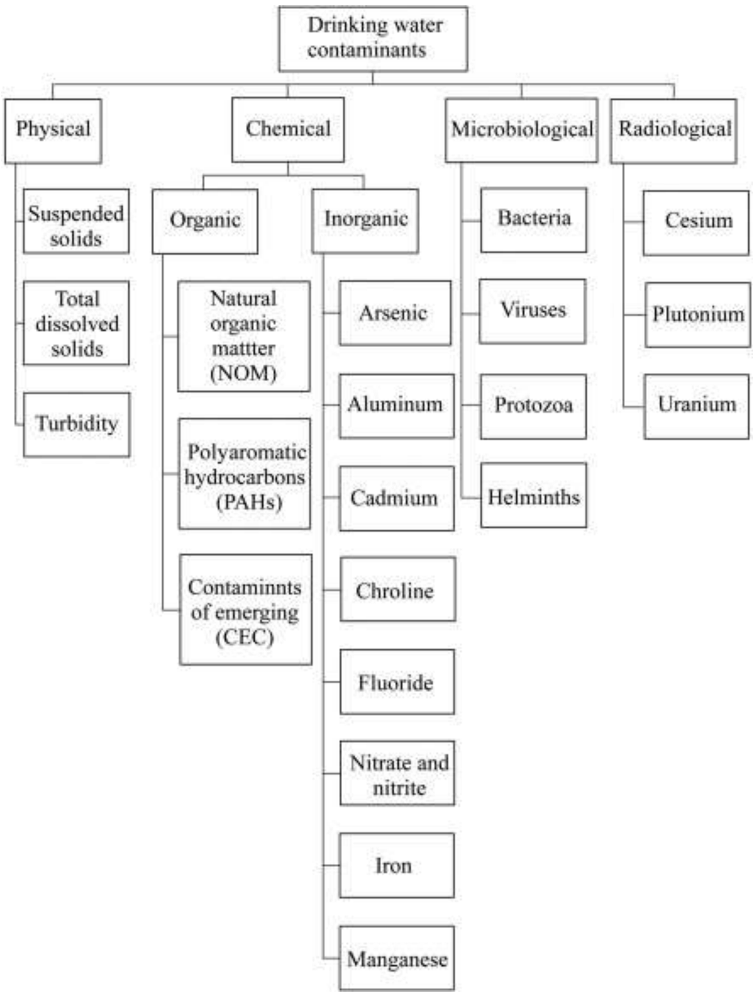
It is not only the water quantity that matters, the quality of water we use is also equally important (Musie & Gonfa, 2023). Most of the countries in the world suffer from a water deficit and approximately 1.2 billion people drink unclean water, resulting in a high number of deaths (S. Ahuja, 2009). That is why the search for alternatives sources so as the to cover the demand of this resource and its management is one of the greatest global challenges of this century.

1.2 Water contaminants

Water pollution, by definition, is the contamination of available water by pollutants or alien materials that lead to death and disease of livestock, aquatic life and humans (Elehinafe *et al.*, 2022). The common sources of water pollution can vary from wholly natural to man-made sources such as release of domestic and industrial wastewaters. Many industries, including textile, aquaculture, paper, agricultural production, energy production, pharmaceutical and so on, would produce a large amount of polluted wastewater (Xu *et al.*, 2023).

Depending on the origin, wastewaters could have various types of water pollutants in varying concentrations include, among others, organic, inorganic pollutants, suspended solids, pathogens, nutrients or even radioactive pollutants (Figure 1) (Singh *et al.*, 2020). Inorganic and organic pollutants are main contaminants in wastewater (Wasewar *et al.*, 2020).

Figure 1. Types of water pollutants



Source: Shah et al., 2023

Organic pollutants are persistent in nature, they can travel far-off and remain deposited and contribute to the toxicity of water systems and the environment (Ghaffar *et al.,* 2023). They are emitted from sewage, urban wastewater, industrial wastewater and agricultural waste. Consequently, some of the common organic pollutants are organic dyes, polychlorinated biphenyls (PCBs), aromatic hydrocarbons (PAHs), pesticides, herbicides, petroleum, and organo-chlorine pesticides (OCPs). They are hydrophobic chemicals that survive in water systems for a long time and are associated with sediments (Masindi & Muedi, 2018; Touliabah *et al*., 2022).

Furthermore, one group of organic pollutants called emerging pollutants (EPs) has gained attention in recent years. Emerging contaminants are primarily organic chemicals found in aquatic systems and the major sources of this pollutants are pharmaceuticals, personal care products, pesticides, and flame retardants (Dubey *et al.,* 2023). Dyes, pharmaceuticals, phenolic contaminants, and personal care products can be considered the most critical emerging organic pollutants, they can adversely affect the ecology and human health (Mohammadi *et al.,* 2022).

On the other hand, inorganic pollutants are usually substances of mineral origin, with metals, salts and minerals being examples (Masindi & Muedi, 2018). Commonly found inorganic contaminants of water include arsenic, fluoride, iron, nitrate, heavy metals, and their presence at more than permissible levels degrades water potability for living organisms (Srivastav & Ranjan, 2020). The high levels of inorganic nitrogen pollutants (nitrate, nitrite, ammonium) and inorganic phosphates in water lead to many health problems (Singh *et al*., 2020). Moreover, the most studied heavy metals in the wastewater generated by various industries are arsenic, copper, chromium, lead, mercury, nickel, and zinc (Srivastav & Ranjan, 2020).

Other contaminants are biological pollutants (pathogens), they are described as pollutants which exist because of humanity's actions and impact on the quality of aquatic environment. This type of pollutants are small microbes that cause disease, including bacteria, viruses, pillows, and certain parasites (Singh *et al*., 2020). These pathogens can cause water-borne diseases like jaundice, diarrhea, cholera, typhoid, nosocomial infections, giardiasis, etc. (Chakraborty *et al*., 2023).

All the three categories of contaminants mentioned above if left untreated or inadequately treated directly affect and impact the environment. The degree of impact depends on the type and concentration of the contaminants (Sharma *et al*., 2019).

Besides the contaminants in water, esthetic water quality is also extremely important. Unpleasant odors, unpalatable taste (e.g., bitter, salty, and metallic), and unappealing appearance/color of water do not pose any serious public health threats but render the consumption of water difficult (Palansooriya *et al*., 2020).

1.3 Water quality

Water quality problems, are rapidly emerging as a result of urbanization, increasing the variety and number of microbial pathogens, pollutants, and nutrients in receiving water bodies (Salerno *et al*., 2018). The quality of water can be described in terms of physical, chemical and biological contaminants, and the evaluation of water quality is essential for water resource management (Yan *et al*., 2022). Many indices for assessing surface water quality (e.g., water quality indices (WQIs), trophic status indices (TSIs), and heavy metal indices (HMIs)) have been designed to assess water quality (Yan *et al*., 2022).

The WQI can be used effectively to represent water quality, it allows to estimate in general the degree of purity or contamination of a sample or an effluent (Valladares-Cisneros *et al.,* 2018). The general parameters used to calculate WQI are dissolved oxygen (DO), pH, temperature, coliforms, specific conductance, alkalinity and chloride. Nevertheless, based on the situation in specific areas many modifications have been considered for WQI, generating different WQIs (Tyagi *et al.,* 2020). For this reason, specific determinations must be made to distinguish the individual concentration of the compounds of interest according with the region.

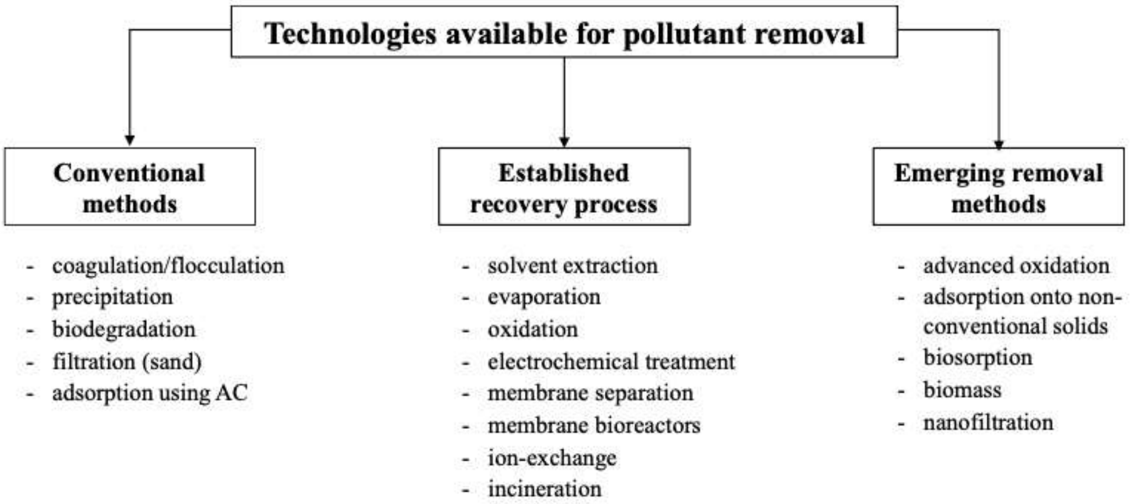
Different water quality evaluation indices can be selected to assess the water quality levels based on the situation in a specific area. The trophic state index (TSI) and trophic level index (TLI) are commonly used methods for evaluating the eutrophication state of lakes and reservoirs (Ding *et al*., 2021). For the other hand, in aquatic ecosystems where exist an excess number of heavy metals that can be a risk for human health, the analysis of dissolved metals in water is a useful tool for assessing the state of pollution (Alves *et al*., 2014). The most widely used HMI for analyzing the exposure risk of heavy metals is the US Environmental Protection Agency (USEPA) guidance (Saha *et al*., 2017; Yan *et al*., 2022).

1.4 Wastewater treatment methods

Various methods are used to treat contaminated water, these techniques frequently incorporate physical, chemical, and biological procedures that successfully treat water in several ways (Nishat *et al*., 2023). However, the type of treatment to be used depends on the environment where the wastewater would be discharged and the type of impact it would have on this environment.

A multitude of techniques classified in conventional methods, established recovery processes and emerging removal methods can be used (Figure 2). The main treatment methods are coagulation and flocculation, evaporation, adsorption, ion exchange, membrane-based purification, catalytic methods, and biological methods (biodegradation) (Mohammadi *et al*., 2022). Additionally, individual treatments can have combined each other in treatment schemes categorized into three main classes: primary, secondary, and tertiary schemes.

Figure 2. Methods for water treatments



Source: Crini & Lichtfouse, 2019a.

Generally, primary treatments are design to remove organic and inorganic solids, only those pollutants which have the tendency to float or settle under the influence of gravity (Sharma *et al*., 2019). Primary treatment consists of temporarily holding the sewage in a quiescent basin where heavy solids can settle to the bottom while oil, grease and lighter solids float to the surface (Rawat *et al.*, 2011).

On the other hand, secondary treatment consists in biological process where dissolved or suspended organic matter are remove by microorganisms. Secondary treatment is typically performed by indigenous, water-borne microorganisms in a managed habitat (Rawat *et al*., 2011). The process carried out two major ways aerobic and anaerobic conditions with the action of microorganisms (Sathya *et al*., 2023). Tertiary treatment scheme popularly known as effluent polishing is employed to remove plant nutrients like phosphorous and nitrogen which are responsible for eutrophication of water bodies (Sharma *et al*., 2019). The tertiary treatment employs physical, chemical and biological procedures.

1.5 Filtration and adsorption

Filtration is the process of removing contaminants where the polluted water enters the top of the filter vessel, flows through the filter medium which retains solids and water passes through the lower section, the driving force in filtration can be pressure gradient, such as gravity (Saravanan *et al.,* 2021). This technology is a physical separation technique using a selectivity mechanism to eliminate particles and organics from wastewater which generates an effluent with great quality and low pollutants (Keyvan Hosseini *et al*., 2023).

Particle and membrane filtrations are the two common filtration types, varying in removal contaminant size (Song *et al*., 2023). The process of membrane filtration relies on the use of a semi-permeable membrane that allows only water to pass through it while withholding substances such as suspended and dissolved solids present in water (Al-Ghouti *et al.,* 2023). This type includes microfiltration (MF), ultrafiltration (UF) and nanofiltration (NF) membranes.

In granular filtration, water passes through a filter consisting of a packed bed of granular materials (Simate, 2015). Filters combine the filtration operation with adsorption, using filtration media that in turn act as adsorbents. Filtration media could be in the form of sand, gravel, fine mesh and many others (Oteng-Peprah *et al*., 2018). Moreover, the adsorption capacity of the filtration media towards pollutants ions is associated with the presence of a higher number of binding sites on the media surface.

Adsorption is a mass transfer process that involves the accumulation of molecules of liquid on a solid surface and becomes bound through physical or chemical connections (Mishra *et al*., 2018; Nishat *et al*., 2023). In physical adsorption, the particles of adsorbate (the substance which is adsorbed) attach to the surface of the adsorbent (the adsorbing material) by forces like van der Waals forces and hydrogen bonding. Conversely in chemisorption, the adsorbate-adsorbent attachment occurs by relatively stronger forces such as an ionic bond or a chemical bond (Al-Ghouti *et al*., 2023).

The adsorbents include nano-sized metal oxides (NMOs), activated carbon, clay minerals, biomass, agricultural waste, and other substances (Nishat *et al*., 2023). The capacity of adsorbent for the adsorption process depends on adsorbent dosage, concentration of pollutants, temperature, pH and contact time (Saravanan *et al*., 2021). Thus, the combination of filtration with other unitary processes, such as adsorption that uses a filtration medium as an adsorbent, proposes a better performance in the removal of pollutants from residual waters.

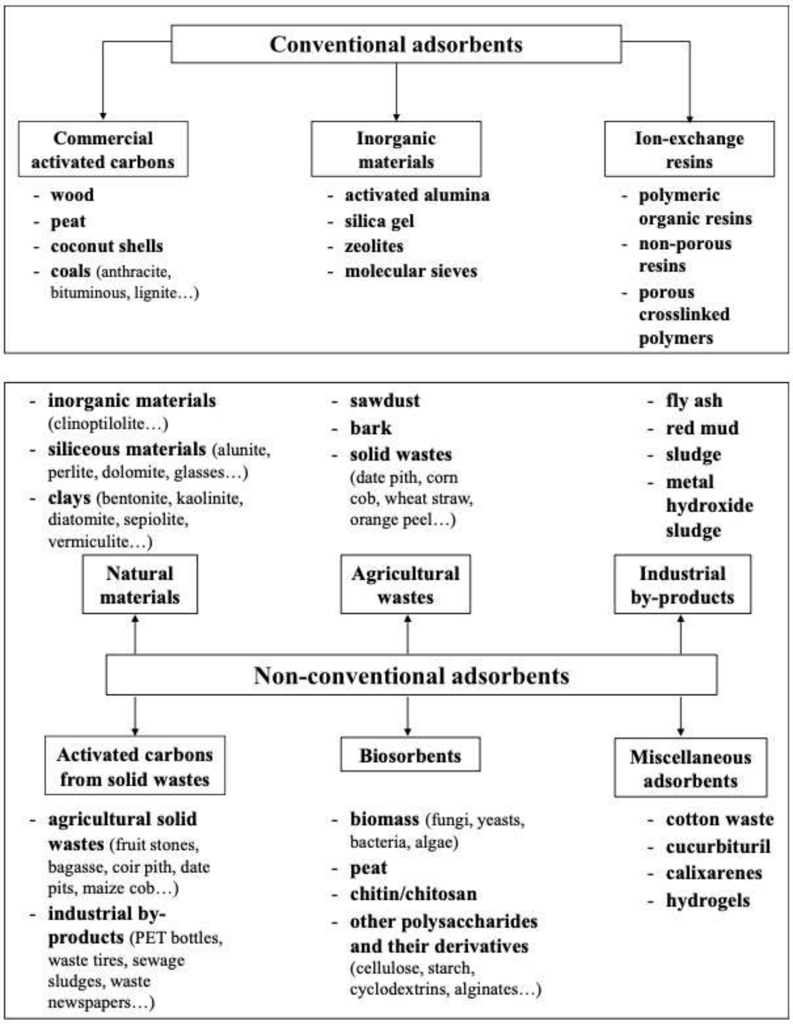
1.6 Adsorbents

Adsorbents are the solid materials that allows liquid or gaseous molecules to bind to its surface and are used for the removal of toxic pollutants from the wastewater or industrial effluents (Abegunde *et al*., 2020; Saravanan *et al*., 2021). Generally, adsorbent's performance depends on the physicochemical properties of the adsorbent surface, solution conditions, as well as that of the soluble substances (Mpatani *et al*., 2021).

An ideal adsorbent should possess a wide surface area and a small volume. Furthermore, a good adsorbent material must include high mechanical strength, chemical and thermal stability, high porosity and low pore diameter leading to increase exposed surface area and hence suitable surface chemistry giving rise to high adsorption capacity (Abegunde *et al*., 2020; Amalina *et al*., 2022).

There are a variety of adsorbents existing in different nature which can either be utilized in different structures, adsorbents are generally utilized in the form of spherical pellets, rods, moldings, or monoliths, depending on the filter configuration (Amalina *et al*., 2022; Chai *et al*., 2021). Natural and synthetic adsorbents are the two types of adsorbents classified based on the source from which they obtained. However, another simplified classification, can be used as follows: conventional and non-conventional.

Figure 3. Conventional and non-conventional adsorbents



Source: Crini et al., 2019b

1.6.1 Conventional adsorbents

Mainly comprise by activated carbons, ion-exchange resins, and inorganic compounds like activated aluminas, silica gel, and zeolites (Figure 3). They are readily available in the nature, easy to use and are widely applied for the treatment of wastewater and in aquaculture (Mangla *et al.*, 2022). In addition, these materials are previously treated and once used, they need to be regenerated to recover their properties (Valladares-Cisneros *et al.*, 2018).

Activated carbon (AC) is a porous, amorphous solid made up of microcrystallites with a graphite lattice. AC is produced from a carbon-rich precursor (coal, coconut shell and wood) by removing the vast bulk of volatile non-carbon components and a portion of the native carbon content via thermal or chemical processes (Amalina *et al.*, 2022; Chai *et al.*, 2021). High degree of micro porosity, well developed surface area, and high adsorption capacity are the key features of ACs (both granular and powdered) that make them suitable as adsorbent for the removal of organic contaminants (Ahmed *et al.*, 2015).

Ion-exchange resins are solid materials that provide path for the movement of ions from their surface to the solvent and vice versa (Ahmed *et al.*, 2015). The advantages of this materials include no loss of adsorbent on regeneration, reclamation of solvent after use and the removal of soluble contaminants at trace levels (Crini *et al.,* 2019b).

On the other hand, zeolites are crystalline aluminium, silicon and oxygen minerals. They have cavities and small chambers inside which small cations, water molecules and other species could be trapped and, in addition, act as cation exchangers (Mangla *et al.*, 2022). Therefore, minerals materials such as zeolites are considered highly effective adsorbents for trace element removal from aqueous solutions because of its characteristics (Al-Ghouti *et al.*, 2023).

Despite the availability, easy to use and high adsorption power of conventional materials, they hold some limitations such as high production costs and some adsorbents are not efficient for large-scale treatment process.

1.6.2 Unconventional adsorbents

Although conventional materials are the usual adsorbents for contamination removal, their high cost and regeneration restricts their application. As a result, alternate solutions for non-conventional adsorbents, mainly organic products and by-products, industrial and agricultural origin and from forest industries (green adsorbents), have been proposed, studied and implemented as economical and effective adsorbents (Rudi *et al.*, 2020).

The various non-traditional adsorbents include biochar, natural material such as clays, biomass, industrial by-products such as red mud, biopolymers (chitosan, cellulose, lignin, pectin, starch), and some other miscellaneous adsorbents (Figure 3). All these materials are interesting because they are available in nature in large quantities, inexpensive, and may have potential as complexing materials due to their physicochemical characteristics and particular structure (Crini *et al.*, 2019b). Some of them are described below.

Zeolite is a crystalline hydrated aluminosilicate with three-dimensional structures, made up of a grid of interconnected tunnels creating a large surface area for cation exchange and adsorption. Moreover, natural zeolites vary widely in their chemical composition, a product of their origin and deposition in nature. A common characteristic of their chemical compositions is the presence of O, Si, Al, as fundamental elements and Ca, Mg, Ba, Na and K as exchangeable cations (Jiménez-Cedillo, 2004).

Pumicite, also called pumice, is a porous volcanic rock, with a structure formed by multiple pores and closed voids. The porosity of pumicite allows it to function as an absorbent. Moreover, its chemical composition, 65.90% silicic anhydride, 11.20% aluminum oxide, 1.25% ferric oxide, 0.52% magnesium oxide, 2.10% sodium oxide and 3.20% potassium oxide prevail, so it has great chemical reactivity (Cornejo Soldevilla, 2015). The modified or activated pumice has good ionic exchange and adsorption capacity for chemical contaminants such as fluorides (Sepehr *et al.*, 2013) and dyes (Samarghandi *et al.*, 2012).

Tezontle is a porous, inert volcanic rock, neutral pH, low ionic exchange capacity (IEC) and moisture retention capacity. The elemental composition of the tezontle shows that it contains O, Si, Al, Ca, C, Fe, Mg and Na (Trejo-Téllez *et al*., 2013). The presence of iron oxides gives it a red or black color, characteristic depending on the presence of hematite or magnetite (Otazo *et al*., 2011). The natural red tezontle was used to evaluate the removal of cadmium ions (Cd2+) finding a total adsorption capacity of 6.62 mg/g (Ponce-Lira, 2018).

Dolomite is a sedimentary rock; a carbonate of calcium and magnesium that makes up about 2% of the earth's crust. Its chemical formula is ($CaMg(CO_3)_2$); it contains 30.41% CaO, 21.86% MgO and 47.73% CO_2, in its purest form (Dirección General de Desarrollo Minero, 2017). Studies where dolomite has been used as a metal ion adsorbent have demonstrated its excellent ionic exchange properties (Ivanets *et al.*, 2016).

Corn straw consists of the leaves, stalks, and corn cob (*Zea mays ssp. Mays L.*) left in a field after harvest. It is a fibrous material with a high lignification state, 95.8 % dry matter and with a mineral content of Cu, Fe, Mn, Zn (Arrieche & Mora, 2005; De Blas *et al.*, 2013; Fuentes *et al*., 2001). Corn straw as biosorbent for plumb and cadmium in wastewater presented an adsorption capacity of 4.27 and 3.43 mg/g according to the Langmuir model (Astudillo *et al*., 2020).

The fruit of the coconut tree *Cocos nucifera L.* is formed by a thick layer that makes up 35% of the coconut called mesocarp, lignocellulosic material, composed of hard multicellular fibers. Lignin, cellulose and hemicellulose give it good absorption and water retention capacity (Reyes, 2016). Therefore, the adsorption of Cr (VI) has been reported using the shell of the fruit of the *Cocos nucifera L.* plant as organic biomass, with removal values of 93.71 to 96.85 % (Pérez Silva *et al*., 2014).

Biocalcium from eggshells is made up of calcium carbonate, calcium phosphate and magnesium carbonate. Additionally, contains minerals such as sodium, zinc, magnesium, manganese, iron, aluminum, boron and copper. The use of biocalcium as an adsorbent material in the elimination of contaminants present in wastewater has had excellent results. For example, the adsorption capacity of the eggshell membrane in textile dyes has been reported, achieving a sorption greater than 81.8 % in aqueous solution (Arami *et al.*, 2006).

2 Materials and methods

The materials that were used in the filtration system were zeolite, pumicite, tezontle, dolomite, ground corn straw (GCS), coconut fiber, biocalcium and olote. The materials that make up the beds of the filter bed were obtained locally; washed, dried and sieved. The characteristics of each material are shown in Table 1. The particle size was determined by sieving through US standard steel mesh sieves number 20 and 40, obtaining a size of 0.850-0.425 mm in all materials.

The graywater used in the different tests was obtained from a laundry, with a washing load capacity of 208 kg/d (Table 2). The inputs used are commercial detergents and fabric softeners. Hence, ten liters of graywater was collected daily for one week, stored refrigerated and continuous agitation. Four identical filter columns made of clear acrylic were used. The height of each column was 90 cm and the diameter 5 cm. A glass wool layer was attached to the bottom of each filter. The filters were fixed with a wooden support. A 50 L capacity feed tank was raised from the floor and connected to a distributor (pipe) with four outlets over the four filters.

Table 1. Characteristics of the bed material in the filtration system

Filter material	Apparent density (kg/m^3)	Porosity (%)	Filtration Velocity (mL/min cm^2)
Zeolite	0.689	64.39	3.99
Pumicite	0.507	63.79	3.44
Tezontle	0.857	64.31	20.41
Dolomite	1.253	53.70	3.48
Ground corn straw	0.451	68.74	1.55
Coconut fiber	0.077	60.75	17.38
Biocalcium	0.919	44.57	8.36
Olote	0.096	68.37	21.71

Source: Own elaboration

Table 2 Laundry greywater characteristics

Parameter (mg/L)	Greywater used as an influent		
	Maximum	Minimum	Average
DQO	365	312	330.8
SST	597	492	548
SDT	3042	2478	2885.4
Phosphates - (PO_4)	6.5	3.2	9.04
Nitrates - (NO_3)	6.2	2.6	4.3
pH	10.1	8.7	9.6

Source: Own Elaboration

2.1 Samples evaluation

Additionally, filtered samples from the four filters, as well as the feed wastewater sample, were analyzed for total solids (TS), suspended and dissolved solids (SS and DS), chemical oxygen demand (COD), nitrates (NO_3), phosphates (PO_4) and pH. Standard analytical methods and a HACH DR2800 spectrophotometer were used.

3 Filtration systems

A simple completely randomized design (CRD) was carried out (Minitab statistical program), it consisted of four treatments (Factor T: T1, T2, T3, T4), combining 4 support materials and 4 as filtration medium. The efficiency of the combination of said materials in the removal of contaminant load from graywater was evaluated. The study factor will be the filtration medium (organic and inorganic materials) in four different combinations as detailed in Table 3. When combining organic and inorganic materials in a water filter, it is recommended that the organic material be supported by inorganic material. Therefore, the random design was applied at the X-Y-Y-X level according to the indicated factors.

Table 3 Factorial arrangement in a completely randomized design

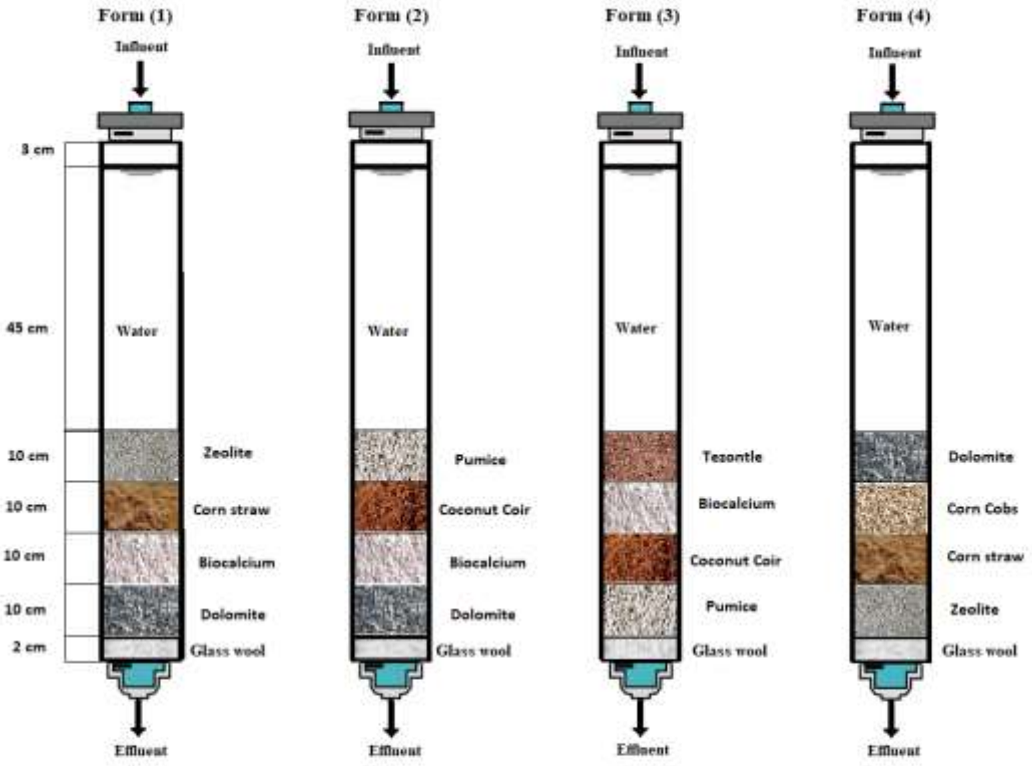
Study factors		
Factor X: Inorganic materials		Factor Y: Organic materials
X_1: *Zeolite*		Y_1: *GCS*
X_2: *Pumicite*		Y_2: *Coconut fiber*
X_3: *Tezontle*		Y_3: *Biocalcium*
X_4: *Dolomite*		Y_4: *Olote*
Treatment	**Arrangement**	**Description**
T_1	X_1	*Zeolite*
	Y_1	*GCS*
	Y_4	*Biocalcium*
	X_4	*Dolomite*
T_2	X_2	*Pumicite*
	Y_2	*Coconut fiber*
	Y_3	*Biocalcium*
	X_3	*Dolomite*
T_3	X_3	*Tezontle*
	Y_3	*Biocalcium*
	Y_2	*Coconut fiber*
	X_2	*Pumicite*
T_4	X_4	*Dolomite*
	Y_4	*Olote*
	Y_1	*GCS*
	X_1	*Zeolite*

Source: Own Elaboration

3.1 Filter evaluation

Four filter columns with different bed layers, same graywater and a filtration rate established by each filter were installed and operated at laboratory scale and in parallel. Figure 4 shows the media used in the filtration of graywater, whose particle size was 0.425 to 0.850 mm. During the experiment a constant influent was maintained in each filter and a sample was collected from each one at the end of the following times 0.5, 1.0, 2.0, 4.0, 6.0, 12.0 and 24.0 hours. Consequently, the liquid obtained was kept refrigerated for further characterization.

Figure 4. Different configurations of filter media



Source: Own Elaboration

4 Results and discussion

In order to verify the efficiency of the filter beds, physicochemical analyzes of the residual water were carried out after the filtration process. Table 4 shows the results of the greywater quality analysis before filtration (Residual water), after filtration at different times and the filtration velocity in each of the configurations of the materials used separately.

Table 4 Summary of physical-chemical analysis

Parameters (mg/L)	Residual water	Filter 1						
		0.5 h	1.0 h	2.0 h	4.0 h	6.0 h	12.0 h	24.0 h
COD	330.8	86.34	67.15	71.29	73.15	83.68	81.65	79.43
TSS	556	104	84	60	48	52	20	16
TDS	2861	591	492	489	466	447	451	416
Phosphates - (PO_4)	9.04	1.84	1.52	1.45	1.36	1.32	1.25	1.14
Nitrates - (NO_3)	4.3	0.87	0.72	0.69	0.65	0.63	0.59	0.54
pH	10	7.39	7.39	7.38	7.38	7.38	7.38	7.37
Filtration Velocity (mL/min cm^2)		0.97	0.93	0.92	0.91	0.85	0.79	0.73
		Filter 2						
COD	330.8	98.34	79.15	83.29	85.15	95.68	93.65	91.43
TSS	556	124	107.5	88	92	60	24	20
TDS	2861	767	711	671	630	499	463	436
Phosphates - (PO_4)	9.04	1.89	1.627	1.536	1.446	1.356	1.356	1.536
Nitrates - (NO_3)	4.3	1.55	1.4	1.37	1.33	1.31	1.27	1.28
pH	10	7.37	7.39	7.40	7.39	7.39	7.41	7.40
Filtration Velocity (mL/min cm^2)		0.80	0.83	0.85	0.78	0.76	0.61	0.60

		Filter 3						
COD	330.8	108.34	89.15	93.29	95.15	105.68	103.65	101.43
TSS	556	56	60	44	32	28	20	20
TDS	2861	459	416	427	395	388	383	347
Phosphates - (PO_4)	9.04	2.15	2.63	2.54	1.85	1.96	1.56	1.74
Nitrates - (NO_3)	4.3	1.1	0.95	0.92	0.89	0.86	0.82	0.87
pH	10	7.33	7.34	7.37	7.36	7.35	7.38	7.36
Filtration Velocity (mL/min cm^2)		0.90	0.90	0.88	0.86	0.83	0.78	0.69
		Filter 4						
COD	330.8	91.34	82.15	76.29	88.15	88.68	86.65	84.43
TSS	556	95	84	64	57	47	21	19
TDS	2861	613	563.5	549	512.5	443.5	423	391.5
Phosphates - (PO_4)	9.04	1.80	2.28	2.19	1.50	1.61	1.21	1.39
Nitrates - (NO_3)	4.3	0.73	0.58	0.55	0.51	0.49	0.45	0.47
pH	10	7.36	7.37	7.38	7.38	7.37	7.39	7.38
Filtration Velocity (mL/min cm^2)		0.87	0.87	0.86	0.83	0.79	0.70	0.65

Source: Own Elaboration

As is show above, COD before filtration was 330.8 mg/L which significantly decrease to 79.4, 91.4, 101.43 and 84.43 for filter 1,2,3 and 4 respectively. Therefore, the systems achieved removal efficiencies of 69% - 75% after 24 hours, highlighting the filter 1 with the highest percentage.

On the other hand, the pH of effluent ranged from 7.3 – 7.4 in each filter. The process reduced the pH by 26%, the decrease may be due to chemical reactions influenced by a functional group of any filtration medium. Additionally, during adsorption (Vader Waal forces of attraction) there is the possibility of cations and anions being released into the system, keeping pH in the range (Tusiime *et al.*, 2022). The values obtained are in agreement with results reported before, which adsorption occurs in pH range of 6.5-8 (Christova-Boal *et al.*, 1996; Fernando *et al.*, 2009; Finley *et al.*, 2009).

Other parameters such as TSS and TDS were also reduced by the filtration process. For TSS, the filter 1 presented the highest removal efficiency with 97.12% at 24 h. However, the highest TDS removal efficiency was achieved with the filter 3 with 87% at 24 h. (Finley *et al.*, 2009), obtained similar values of TDS in the treatment of a graywater from shower and washer machines.

Finally, initial values of nutrients were reduced to 84-87% and 87-89% for PO_4 and NO_3, respectively. Having a better and similar performance the filters 1 and 3. The study by (Samayamanthula *et al.*, 2019) reported similar minimum concentrations of PO_4 in greywater treated by a filter with different filtration media. Similarly, the study by (Parjane & Sane, 2011) reported comparable concentrations of NO_3 in greywater treatment.

The most efficient configuration was the filter 1, having a removal percentage of 75%, 97.1%, 87% and 87% for COD, TSS, PO4 and NO3, respectively. Filter 4 has a similar behavior, which has the peculiarity of sharing 3 of the 4 materials of filter 1, so it is possible to infer that these 3 materials have the best adsorption capacity. On the other hand, the one that did not have such high removal percentages is filter 2, which has different materials such as pumicite and coconut fiber. The materials and their conformation are an important point to consider for the development of filters capable of removing contaminants from graywater.

5 Conclusion

This study developed and evaluated a filtration system that uses different conformations of unconventional materials in order to obtain better filter performance in graywater treatment. According to the results obtained, the physicochemical parameters showed that the filter beds were effective in removing contaminants after 24 hours through filter media such as zeolite, pumicite, tezontle, dolomite, ground corn straw (GCS), coconut fiber, biocalcium and olote. The configuration with the highest removal percentage in most of the parameters studied was the filter 1, having a removal percentage of 75%, 97.1%, 87% and 87% for COD, TSS, PO_4 and NO_3, respectively. The results reinforce the potential of nonconventional adsorbents in the wastewater treatment and offers a full treatment of greywater with available materials.

6 Acknowledgments

To the Tecnológico de Estudios Superiores de Jocotitlán (TESJo) for the facilities for the use of laboratory equipment.

7 References

Abegunde, S. M., Idowu, K. S., Adejuwon, O. M., & Adeyemi-Adejolu, T. (2020). A review on the influence of chemical modification on the performance of adsorbents. Resources, Environment and Sustainability, 1(July), 100001. https://doi.org/10.1016/j.resenv.2020.100001

Ahmed, M. B., Zhou, J. L., Ngo, H. H., & Guo, W. (2015). Adsorptive removal of antibiotics from water and wastewater: Progress and challenges. Science of the Total Environment, 532, 112–126. https://doi.org/10.1016/j.scitotenv.2015.05.130

Ahuja, S. (2009). Handbook of water purity and quality (S. B. T.-H. of W. P. and Q. Ahuja (ed.); pp. 1–16). Academic Press. https://doi.org/10.1016/B978-0-12-374192-9.00001-7

Al-Ghouti, M. A., Ashfaq, M. Y., Khan, M., Al Disi, Z., Da'na, D. A., & Shoshaa, R. (2023). State-of-the-art adsorption and adsorptive filtration based technologies for the removal of trace elements: A critical review. Science of The Total Environment, 895(April), 164854. https://doi.org/10.1016/j.scitotenv.2023.164854

Alves, R. I. S., Sampaio, C. F., Nadal, M., Schuhmacher, M., Domingo, J. L., & Segura-Muñoz, S. I. (2014). Metal concentrations in surface water and sediments from Pardo River, Brazil: Human health risks. Environmental Research, 133, 149–155. https://doi.org/10.1016/j.envres.2014.05.012

Amalina, F., Razak, A. S. A., Krishnan, S., Zularisam, A. W., & Nasrullah, M. (2022). The effects of chemical modification on adsorbent performance on water and wastewater treatment - A review. Bioresource Technology Reports, 20(October), 101259. https://doi.org/10.1016/j.biteb.2022.101259

Arami, M., Yousefi Limaee, N., & Mahmoodi, N. M. (2006). Investigation on the adsorption capability of egg shell membrane towards model textile dyes. Chemosphere, 65(11), 1999–2008. https://doi.org/10.1016/j.chemosphere.2006.06.074

Arrieche, I., & Mora, O. (2005). Efecto de la aplicación de residuos orgánicos sobre el cultivo del maíz en suelos degradados del Estado Yaracuy, Venezuela. Bioagro, 17(3), 155–159. http://ve.scielo.org/scielo.php?script=sci_arttext&pid=S1316-33612005000300005&lng=es&tlng=es

Astudillo, S., L., V., J., A., & C., C. (2020). Evaluación del poder biosorbente de la hoja de maíz en la remoción de metales pesados. Afinidad. Journal of Chemical Engineering Theoretical and Applied Chemistry, 77(591 SE-Articles). https://raco.cat/index.php/afinidad/article/view/377165

Chai, W. S., Cheun, J. Y., Kumar, P. S., Mubashir, M., Majeed, Z., Banat, F., Ho, S. H., & Show, P. L. (2021). A review on conventional and novel materials towards heavy metal adsorption in wastewater treatment application. Journal of Cleaner Production, 296, 126589. https://doi.org/10.1016/j.jclepro.2021.126589

Chakraborty, U., Kaur, G., Rubahn, H.-G., Kaushik, A., Ram Chaudhary, G., & Kumar Mishra, Y. (2023). Advanced Metal Oxides Nanostructures to Recognize and Eradicate Water Pollutants. Progress in Materials Science, 101169. https://doi.org/10.1016/j.pmatsci.2023.101169

Christova-Boal, D., Eden, R. E., & McFarlane, S. (1996). An investigation into greywater reuse for urban residential properties. Desalination, 106(1), 391–397. https://doi.org/10.1016/S0011-9164(96)00134-8

Cornejo Soldevilla, D. M. (2015). Determinación de la eficiencia de remoción de la dbo de agua residual doméstica mediante la utilizanción de un biofiltro de piedra pómez. http://dspace.unitru.edu.pe/handle/UNITRU/3261

Crini, G., & Lichtfouse, E. (2019a). Advantages and disadvantages of techniques used for wastewater treatment. Environmental Chemistry Letters, 17(1), 145–155. https://doi.org/10.1007/s10311-018-0785-9

Crini, G., Lichtfouse, E., Wilson, L. D., & Morin-Crini, N. (2019b). Conventional and non-conventional adsorbents for wastewater treatment. Environmental Chemistry Letters, 17(1), 195–213. https://doi.org/10.1007/s10311-018-0786-8

De Blas, C., Mateos, G. G., & Rebollar, P. G. (2013). Fundación Española para el desarrollo de la nutrición animal. Necesidades Nutricionales Para Ganado Porcino. 2nd Ed. Madrid: FEDNA. https://www.fundacionfedna.org/sites/default/files/Normas PORCINO_2013rev2_0.pdf

Ding, Y., Zhao, J., Peng, W., Zhang, J., Chen, Q., Fu, Y., & Duan, M. (2021). Stochastic trophic level index model: A new method for evaluating eutrophication state. Journal of Environmental Management, 280(December 2020), 111826. https://doi.org/10.1016/j.jenvman.2020.111826

Dirección General de Desarrollo Minero. (2017). Perfil de Mercado de la Dolomita. Subsecretaria de Mineria de Mexico, 53. https://www.gob.mx/cms/uploads/attachment/file/287798/Perfil_Dolomita_2017.pdf

Dubey, S., Chen, C. W., Haldar, D., Tambat, V. S., Kumar, P., Tiwari, A., Singhania, R. R., Dong, C. Di, & Patel, A. K. (2023). Advancement in algal bioremediation for organic, inorganic, and emerging pollutants. Environmental Pollution, 317(December 2022), 120840. https://doi.org/10.1016/j.envpol.2022.120840

Elehinafe, F. B., Agboola, O., Vershima, A. D., & Bamigboye, G. O. (2022). Insights on the advanced separation processes in water pollution analyses and wastewater treatment – A review. South African Journal of Chemical Engineering, 42(August), 188–200. https://doi.org/10.1016/j.sajce.2022.08.004

Eriksson, E., Auffarth, K., Henze, M., & Ledin, A. (2002). Characteristics of grey wastewater. Urban Water, 4(1), 85–104. https://doi.org/10.1016/S1462-0758(01)00064-4

Fernando, A., Monteiro, S., Pinto, F., & Mendes, B. (2009). Production of biosorbents from waste olive cake and its adsorption characteristics for Zn2+ ion. Sustainability, 1(2), 277–297. https://doi.org/10.3390/su1020277

Finley, S., Barrington, S., & Lyew, D. (2009). Reuse of Domestic Greywater for the Irrigation of Food Crops. Water, Air, and Soil Pollution, 199(1), 235–245. https://doi.org/10.1007/s11270-008-9874-x

Fuentes, J., Magaña, C., Suárez, L., Peña, R., Rodríguez-Herrera, S. A., & de la Rosa, B. O. (2001). Análisis químico y digestibilidad “in vitro” de rastrojo de maíz (Zea mays L.). Agronomía Mesoamericana, 12(2), 189–192. https://www.redalyc.org/articulo.oa?id=43712209

Ghaffar, I., Hussain, A., Hasan, A., & Deepanraj, B. (2023). Microalgal-induced remediation of wastewaters loaded with organic and inorganic pollutants: An overview. Chemosphere, 320, 137921. https://doi.org/10.1016/J.CHEMOSPHERE.2023.137921

Grzegorzek, M., Wartalska, K., & Kaźmierczak, B. (2023). Review of water treatment methods with a focus on energy consumption. International Communications in Heat and Mass Transfer, 143(December 2022). https://doi.org/10.1016/j.icheatmasstransfer.2023.106674

Ivanets, A. I., Kitikova, N. V., Shashkova, I. L., Oleksiienko, O. V., Levchuk, I., & Sillanpää, M. (2016). Using of phosphatized dolomite for treatment of real mine water from metal ions. Journal of Water Process Engineering, 9, 246–253. https://doi.org/10.1016/j.jwpe.2016.01.005

Jiménez-Cedillo, M. J. (2004). Caracterización de minerales zeolíticos mexicanos. Toluca, Estado de México, México: Universidad Autónoma Del Estado De México, Facultad De Química. https://inis.iaea.org/collection/NCLCollectionStore/_Public/37/022/37022042.pdf

Keyvan Hosseini, M., Liu, L., Keyvan Hosseini, P., Lee, K., & Miao, J. (2023). Performance evaluation of a pilot-scale membrane filtration system for oily wastewater treatment: CFD modeling and scale-up design. Journal of Water Process Engineering, 52(January), 103570. https://doi.org/10.1016/j.jwpe.2023.103570

López, C., Moreira, M. T., Feijoo, G., & Lema, J. M. (2007). Tecnologías para el tratamiento de efluentes de industrias textiles. Afinidad, 64(531), 561–573. https://www.researchgate.net/publication/229058887_Tecnologias_para_el_tratamiento_de_efluentes_de_industrias_textiles

Mangla, D., Annu, Sharma, A., & Ikram, S. (2022). Critical review on adsorptive removal of antibiotics: Present situation, challenges and future perspective. Journal of Hazardous Materials, 425(November 2021), 127946. https://doi.org/10.1016/j.jhazmat.2021.127946

Manouchehri, M., & Kargari, A. (2017). Water recovery from laundry wastewater by the cross flow microfiltration process: A strategy for water recycling in residential buildings. Journal of Cleaner Production, 168, 227–238. https://doi.org/10.1016/j.jclepro.2017.08.211

Masindi, V., & Muedi, K. L. (2018). Environmental contamination by heavy metals. Heavy Metals, 10, 115–132. https://doi.org/10.5772/intechopen.76082

Mishra, S., Chowdhary, P., & Bharagava, R. N. (2018). Conventional methods for the removal of industrial pollutants, their merits and demerits. In Emerging and Eco-Friendly Approaches for Waste Management. https://doi.org/10.1007/978-981-10-8669-4_1

Mohammadi, S. A., Najafi, H., Zolgharnian, S., Sharifian, S., & Asasian-Kolur, N. (2022). Biological oxidation methods for the removal of organic and inorganic contaminants from wastewater: A comprehensive review. Science of the Total Environment, 843(April). https://doi.org/10.1016/j.scitotenv.2022.157026

Molina García, M. E. (2016). Elaboración de un filtro artesanal de agua utilizando materiales no convencionales, evaluando su eficiencia para la disminución de los niveles de contaminación de aguas residuales generada por una lavadora de autos. Universidad Técnica de Ambato. Facultad de Ingeniería Civil y Mecánica. http://repositorio.uta.edu.ec/jspui/handle/123456789/24606

Mpatani, F. M., Han, R., Aryee, A. A., Kani, A. N., Li, Z., & Qu, L. (2021). Adsorption performance of modified agricultural waste materials for removal of emerging micro-contaminant bisphenol A: A comprehensive review. Science of the Total Environment, 780, 146629. https://doi.org/10.1016/j.scitotenv.2021.146629

Musie, W., & Gonfa, G. (2023). Fresh water resource, scarcity, water salinity challenges and possible remedies: A review. Heliyon, e18685. https://doi.org/10.1016/j.heliyon.2023.e18685

Nishat, A., Yusuf, M., Qadir, A., Ezaier, Y., Vambol, V., Ijaz Khan, M., Ben Moussa, S., Kamyab, H., Sehgal, S. S., Prakash, C., Yang, H. H., Ibrahim, H., & Eldin, S. M. (2023). Wastewater treatment: A short assessment on available techniques. Alexandria Engineering Journal, 76, 505–516. https://doi.org/10.1016/j.aej.2023.06.054

Oki, T., & Quiocho, R. E. (2020). Economically challenged and water scarce: identification of global populations most vulnerable to water crises. International Journal of Water Resources Development, 36(2–3), 416–428. https://doi.org/10.1080/07900627.2019.1698413

Orlowsky, B., Hoekstra, A. Y., Gudmundsson, L., & Seneviratne, S. I. (2014). Today's virtual water consumption and trade under future water scarcity. Environmental Research Letters, 9(7), 74007. https://doi.org/10.1088/1748-9326/9/7/074007

Otazo, E., Ortíz, A., Richards, R., & Ponce, B. (2011). Materiales Funcionales para la Remoción de Iones Metálicos contaminantes del agua. Avances de Impacto, Tecnología y Toxicología Ambiental, 85–118. https://repository.uaeh.edu.mx/bitstream/handle/123456789/11453

Oteng-Peprah, M., Acheampong, M. A., & deVries, N. K. (2018). Greywater Characteristics, Treatment Systems, Reuse Strategies and User Perception—a Review. Water, Air, & Soil Pollution, 229(8), 255. https://doi.org/10.1007/s11270-018-3909-8

Palansooriya, K. N., Yang, Y., Tsang, Y. F., Sarkar, B., Hou, D., Cao, X., Meers, E., Rinklebe, J., Kim, K. H., & Ok, Y. S. (2020). Occurrence of contaminants in drinking water sources and the potential of biochar for water quality improvement: A review. Critical Reviews in Environmental Science and Technology, 50(6), 549–611. https://doi.org/10.1080/10643389.2019.1629803

Parjane, S. B., & Sane, M. G. (2011). Performance of grey water treatment plant by economical way for Indian rural development. International Journal of ChemTech Research, 3(4), 1808–1815. https://sphinxsai.com/Vol.3No.4/chem/pdf/CT=13(1808-1815)OD11.pdf

Pérez Silva, R. M., Calzado Lamela, O., Cascaret Carmenaty, D. A., & Tur Naranjo, E. (2014). Adsorción de Cr (VI) por Cocos nucífera L. en aguas residuales de Fibrocemento en Santiago de Cuba. Revista Colombiana de Biotecnología, 16(1), 9–18. https://doi.org/10.15446/rev.colomb.biote.v16n1.44183

Ponce-Lira, B. (2018). Remoción De Cadmio Mediante Adsorbentes Cerámicos Empacados En Columnas De Lecho Fijo. Agro Productividad, 11(4). https://doi.org/10.32854/agrop.v11i4.282

Qu, X., Brame, J., Li, Q., & Alvarez, P. J. J. (2013). Nanotechnology for a Safe and Sustainable Water Supply: Enabling Integrated Water Treatment and Reuse. Accounts of Chemical Research, 46(3), 834–843. https://doi.org/10.1021/ar300029v

Rawat, I., Ranjith Kumar, R., Mutanda, T., & Bux, F. (2011). Dual role of microalgae: Phycoremediation of domestic wastewater and biomass production for sustainable biofuels production. Applied Energy, 88(10), 3411–3424. https://doi.org/10.1016/J.APENERGY.2010.11.025

Reyes, J. V. (2016). Determination of the efficiency of sawdust and coco fiber used as Biofilter for pollutant removal for the treatment of wastewater. Enfoque UTE, 7(3), 41–56. https://doi.org/10.29019/enfoqueute.v7n3.104

Rudi, N. N., Muhamad, M. S., Te Chuan, L., Alipal, J., Omar, S., Hamidon, N., Abdul Hamid, N. H., Mohamed Sunar, N., Ali, R., & Harun, H. (2020). Evolution of adsorption process for manganese removal in water via agricultural waste adsorbents. Heliyon, 6(9), e05049. https://doi.org/10.1016/j.heliyon.2020.e05049

Saha, N., Rahman, M. S., Ahmed, M. B., Zhou, J. L., Ngo, H. H., & Guo, W. (2017). Industrial metal pollution in water and probabilistic assessment of human health risk. Journal of Environmental Management, 185, 70–78. https://doi.org/10.1016/j.jenvman.2016.10.023

Salerno, F., Gaetano, V., & Gianni, T. (2018). Urbanization and climate change impacts on surface water quality: Enhancing the resilience by reducing impervious surfaces. Water Research, 144, 491–502. https://doi.org/10.1016/j.watres.2018.07.058

Samarghandi, M. R., Zarrabi, M., Noori Sepehr, M., Panahi, R., & Foroghi, M. (2012). Removal of Acid Red 14 by Pumice Stone as a Low Cost Adsorbent: Kinetic and Equilibrium Study. Iranian Journal of Chemistry and Chemical Engineering, 31(3), 19–27. https://doi.org/10.30492/ijcce.2012.5947

Samayamanthula, D. R., Sabarathinam, C., & Bhandary, H. (2019). Treatment and effective utilization of greywater. Applied Water Science, 9, 1–12. https://doi.org/10.1007/s13201-019-0966-0

Saravanan, A., Senthil Kumar, P., Jeevanantham, S., Karishma, S., Tajsabreen, B., Yaashikaa, P. R., & Reshma, B. (2021). Effective water/wastewater treatment methodologies for toxic pollutants removal: Processes and applications towards sustainable development. Chemosphere, 280, 130595. https://doi.org/10.1016/j.chemosphere.2021.130595

Sathya, R., Arasu, M. V., Al-Dhabi, N. A., Vijayaraghavan, P., Ilavenil, S., & Rejiniemon, T. S. (2023). Towards sustainable wastewater treatment by biological methods – A challenges and advantages of recent technologies. Urban Climate, 47(October 2022), 101378. https://doi.org/10.1016/j.uclim.2022.101378

Sepehr, M. N., Sivasankar, V., Zarrabi, M., & Senthil Kumar, M. (2013). Surface modification of pumice enhancing its fluoride adsorption capacity: An insight into kinetic and thermodynamic studies. Chemical Engineering Journal, 228, 192–204. https://doi.org/10.1016/j.cej.2013.04.089

Shah, A., Arjunan, A., Baroutaji, A., & Zakharova, J. (2023). A review of physicochemical and biological contaminants in drinking water and their impacts on human health. Water Science and Engineering, xxx. https://doi.org/10.1016/j.wse.2023.04.003

Sharma, N., Singh, A., & Batra, N. (2019). Modern and Emerging Methods of Wastewater Treatment. Springer Singapore. https://doi.org/10.1007/978-981-13-0149-0_13

Simate, G. S. (2015). The treatment of brewery wastewater for reuse by integration of coagulation/flocculation and sedimentation with carbon nanotubes “sandwiched” in a granular filter bed. Journal of Industrial and Engineering Chemistry, 21, 1277–1285. https://doi.org/10.1016/j.jiec.2014.06.001

Singh, J., Yadav, P., Pal, A. K., & Mishra, V. (2020). Water Pollutants: Origin and Status BT - Sensors in Water Pollutants Monitoring: Role of Material (D. Pooja, P. Kumar, P. Singh, & S. Patil (eds.); pp. 5–20). Springer Singapore. https://doi.org/10.1007/978-981-15-0671-0_2

Song, S., Le-Clech, P., & Shen, Y. (2023). Microscale fluid and particle dynamics in filtration processes in water treatment: A review. Water Research, 233(September 2022), 119746. https://doi.org/10.1016/j.watres.2023.119746

Srivastav, A. L., & Ranjan, M. (2020). Chapter 1 - Inorganic water pollutants (P. Devi, P. Singh, & S. K. B. T.-I. P. in W. Kansal (eds.); pp. 1–15). Elsevier. https://doi.org/10.1016/B978-0-12-818965-8.00001-9

Sun, Y., Nan, Z., Yang, W., & Li, L. (2023). Projecting China’s future water footprints and water scarcity under socioeconomic and climate change pathways using an integrated simulation approach. Climate Services, 30(1), 100385. https://doi.org/10.1016/j.cliser.2023.100385

Touliabah, H. E., El-Sheekh, M. M., Ismail, M. M., & El-Kassas, H. (2022). A Review of Microalgae- and Cyanobacteria-Based Biodegradation of Organic Pollutants. In Molecules (Vol. 27, Issue 3). https://doi.org/10.3390/molecules27031141

Trejo-Téllez, L. I., Ramírez-Martínez, M., Gómez-Merino, F. C., García-Albarado, J. C., Baca-Castillo, G. A., & Tejeda-Sartorius, O. (2013). Evaluación física y química de tezontle y su uso en la producción de tulipán. Revista Mexicana de Ciencias Agrícolas, 4(SPE5), 863–876. https://www.redalyc.org/articulo.oa?id=263128352001

Tusiime, A., Solihu, H., Sekasi, J., & Mutanda, H. E. (2022). Performance of lab-scale filtration system for grey water treatment and reuse. Environmental Challenges, 9(August), 100641. https://doi.org/10.1016/j.envc.2022.100641

Tyagi, S., Sharma, B., Singh, P., & Dobhal, R. (2020). Water Quality Assessment in Terms of Water Quality Index. American Journal of Water Resources, 1(3), 34–38. https://doi.org/10.12691/ajwr-1-3-3

Valladares-Cisneros, M. G., Cárdenas, C. V., Burelo, P. de la C., & Alemán, R. M. M. (2018). Non-conventional absorbers: sustainable alternatives for wastewater treatment. Revista Ingenierías Universidad de Medellín, 16(31 SE-Articles). https://doi.org/10.22395/rium.v16n31a3

Wasewar, K. L., Singh, S., & Kansal, S. K. (2020). Process intensification of treatment of inorganic water pollutants. In Inorganic Pollutants in Water. INC. https://doi.org/10.1016/B978-0-12-818965-8.00013-5

Xu, Y., Zhang, X., Zhao, Y., Wu, Y., Liu, Y., Wang, R., Yang, Y., & Chen, J. (2023). Research status and progress in degradation of organic pollutants via hydrogen evolution reaction and oxygen evolution reaction in wastewater electrochemical treatment. International Journal of Hydrogen Energy, xxxx. https://doi.org/10.1016/j.ijhydene.2023.05.167

Yan, T., Shen, S. L., & Zhou, A. (2022). Indices and models of surface water quality assessment: Review and perspectives. Environmental Pollution, 308(March), 119611. https://doi.org/10.1016/j.envpol.2022.119611