UNIVERSIDAD TÉCNICA DE MANABÍ
Fundada en 1952

LA TÉCNICA
Revista de las Agrociencias

Environmental Protection

Analysis of wastewater treatment technologies: A literature review

Análisis de las tecnologías para el tratamiento de aguas residuales: Una revisión bibliográfica

Authors

*Fabiola Maribel Jiménez Tamayo

Joana Alexandra Moreno López

Mónica Cecibel Encalada Zumba

Evelyn Alejandra Vargas Peralvo

Universidad Estatal Amazónica, El Puyo, Ecuador.

*Correspondence author.

Suggested citation: Jiménez Tamayo, F. M., Moreno López, J. A., Encalada Zumba, M. C. and Vargas Peralvo, E. A. (2024). Analysis of wastewater treatment technologies: A literarture review. *La Técnica*, *14*(2), 103-117. DOI:https://doi.org/ 10.33936/latecnica.v14i2.6467

Received: February 29th, 2024
Accepted: May 15th, 2024
Published: July 22nd, 2024

Abstract

Effective management of effluents generated by the activity is essential to protect public health and conserve the environment, especially when 2.4 billion people still lack access to essential health services. Pollution of water resources in Latin America threatens biodiversity and health, making efficient and sustainable wastewater treatment essential to meet the growing demand for drinking water and comply with stricter environmental regulations. The objective was to identify the main technologies developed for wastewater treatment. The literature review was carried out using the PRISMA methodology, which consists of four stages: identification, selection, eligibility and inclusion. Physical, mechanical, biological, chemical and advanced methods for wastewater treatment were identified. The effectiveness of biological methods, such as activated sludge and constructed wetlands, is emphasized to eliminate organic matter, reaching efficiencies greater than 80% in domestic waters and up to 88% in industrial effluents. The usefulness of physical-chemical processes in the elimination of specific compounds was also highlighted. It is concluded that the combination of technologies in hybrid systems is essential for a comprehensive treatment and the emergence of membranes, such as nanofiltration and ultrafiltration, for the selective elimination of contaminants is noted. Furthermore, the trend towards the use of sustainable processes is highlighted, which includes the use of waste as treatment materials, the generation of useful by-products and the reduction of energy consumption.

Keywords: efficiency; innovation; sanitation; sustainability.

Resumen

Un manejo eficaz de los efluentes generados por la actividad resulta fundamental para proteger la salud pública y conservar el medio ambiente, especialmente cuando 2.400 millones de personas aún carecen de acceso a servicios sanitarios esenciales. La contaminación de los recursos hídricos en Latinoamérica amenaza la biodiversidad y la salud, haciendo esencial el tratamiento eficiente y sostenible de aguas negras para enfrentar la creciente demanda de agua potable y cumplir con regulaciones ambientales más estrictas. El objetivo fue identificar las principales tecnologías desarrolladas para el tratamiento de aguas residuales. La revisión bibliográfica se realizó mediante la metodología PRISMA, la cual, constó de cuatro etapas: identificación, selección, elegibilidad e inclusión. Se identificaron métodos físicos, mecánicos, bilógicos, químicos y avanzados para el tratamiento de aguas residuales. Se enfatizó la efectividad de los métodos biológicos, como lodos activados y humedales construidos, para eliminar la materia orgánica, alcanzando eficiencias superiores al 80% en aguas domésticas y hasta 88% en efluentes industriales. También se destacó la utilidad de procesos físico-químicos en la eliminación de compuestos específicos. Se concluye que la combinación de tecnologías en sistemas híbridos es esencial para un tratamiento integral y se señala la emergencia de membranas, como la nanofiltración y ultrafiltración, para la eliminación selectiva de contaminantes. Además, se subraya la tendencia hacia el uso de procesos sostenibles, que incluyen el aprovechamiento de residuos como materiales de tratamiento, la generación de subproductos útiles y la reducción del consumo energético.

Palabras clave: eficiencia; innovación; saneamiento; sustentabilidad.

Introduction

Progress in public health around the world greatly depends on good hygiene practices, the availability of sanitary installations and reliable waste water management (AR; Peña, 2016). The OMS estimated that 2.400 million people, almost a third of the world's population, do not have access to any kind of sanitary installation (OMS, 2023). This lack of access disproportionately affects rural communities and those in developing countries. According to Wolf et al. (2023) inadequate access to clean water, sanitation services and good hygiene are responsible for 10% of global mortality rates. Moreover, they mentioned that diarrhea is the second cause for infantile mortality in children younger than 5 years old around the world. Likewise, lack of sanitation services also facilitated the spread of diseases such as cholera, dysentery, hepatitis A and poliomyelitis (Rodríguez et al., 2016).

Latin America faces a growing environmental challenge due to the management of AR. As the region's population grows, wastewater generated by domestic, industrial and agricultural activities also rises. These effluentes run directly into the environment and are not previously treated (Rodríguez-Valencia et al., 2022). This practice not only threatens public health by exposing communities to pathogens and toxic substances, but also endangers the region's inmense biodiversity. South America is the home of approximately a third of fresh water sources in the world. Despite the dependance of society on these aquatic ecosystems, they are still affected by the effluents generated by human activity (Sáez et al., 2022). Moreover, water contamination sabotages the use of this resource for agriculture, industry and human consumption, which may have economic repercussions for the countries of the region (Velázquez-Chávez et al., 2022).

Wastewater treatment has gained critical importance in the current context, where the growing demand of drinking water and environmental regulations are more controlled and rigorous. This situation is exacerbated by rapid industrialization and demographic growth, factors which have produced a notable decrease in the availability of vital water resources (Díaz-Cuenca et al., 2012). In an era marked by a growing concern for environmental management strategies and the urgency to face issues in santitation, disease and poverty, it is imperative to develop technologies for wastewater treatment that are not only efficient, but that respect the environment as well (Muga et al., 2008). Adoption and promotion of these sustainable technologies do not only guarantee a supply of cleaner and safer water resources, but also lay the foundations for a more sustainable and ecologically-minded future (Lee et al., 2022).

At the internation stage, specifically in Japan, authors such as Semaha et al. (2023) have developed a biological wastwater transition, from conventional activated sludge (CAS) to activated granular sludge (AGS). These advanced systems are more efficient in eliminating the contaminants and allow reusing the resources in a circular economy. On the other hand, Ewing et al. (2014) carried out studies to take advantage of redox gradients in facultatives lagoons (Pullman, EE. UU.) using lagoon microbial fuel cells to autonomously improve oxygen delivering to the lagoon through airing and operating an air bomb. Lagoon microbial fuel cells (LMFC) were tested as a source of alternative energy for improving wastewater treatment. Rojas-Morales et al. (2016) analyzed the effluents generated by the process of poultry slaughter. This process involved the use of high quantities of water on activities such as blanching, washing, cooling and cleaning, which generated contaminated wastewater. The intent of the study was to investigate the use of activated charcoal as an adsorbent to eliminate contaminants.

In Ecuador, authors such as Peña et al. (2018) treated wastewater from the city of Yaguachi using four facultative lagoons and eight maturation stabilisation ponds. From this system, an 82% decrease of pollutant load for the biochemical demand bond (DBO) and 99% for coliforms. This method is popular due to its simplicity, initial land operational low-cost, and the minimal training required for the working staff. On the

latecnica@utm.edu.ec | Vol. 14, Num. 2 (103-117): July-December, 2024 | DOI: 10.33936/latecnica.v14i2.6467

other hand, Sánchez et al. (2018) carried out studies at the Chasinato ravine in the municipality of Ambato, to determine the efficency of a subsurface flow wastewater treatment system using macrophytes for coliform removal. The presence of this microorganism was an indicator of fecal pollution in the water. Meanwhile, Marín et al. (2015) proposed a solution for wastewater generated by the fish-processing industry in Manta with an anaerobic treatment, a viable solution because it uses microorganisms to oxidize organic matter in the effluents. One of the advantages of this methods is that it produces biogas, which can be used as an energy source, and generates lower quantities of sludge compared to other treatment methods.

Considering this, the aim of this study was to identify the main technologies that have been developed for wastewater treatment.

Materials and methods

The methodology for the literature review was structured in two key stages, using the PRISMA methodology (*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*) explained by Page et al. (2021). Initially, a systematic search in scientific databases, with a strategic selection of keywords. Moreover, the boolean operators like "AND" to interpret concepts, "OR" to expand the search and include synonyms, and "NOT" to exclude undesired words about wastewater treatment, removal efficiency and the sustainability of the process. This stage was oriented towards identifying the literature that discussed wastewater treatments in a significant way. Afterwards, a strict selection criteria was applied, highlighting those studies that did not meet the requirements of relevancy and quality. This procedure assured an exhaustive and meticulous literature review, focused on consolidating a robust knowledge base for the study.

Information gathering

The PRISMA methodology used in this analysis started with the identification stage using research using academic databases such as ScienceDirect, SciELO, MDPI, as well as Google Scholar for extended range. A search strategy was desgined with precisely selected keywords that represented crucial aspects of wastewater treatment such as "water treatment", "purification", "purification systems", following the logic of current research standards in the field. The selection stage was carried out after gathering the literature published up to October 2023, resulting in 263 preliminary documents (figure 1). An exclusion criteria was applied to discard studies with undefined authorship and those that were not directly related to wastewater treatments. The inclusion criteria were based on the direct relevancy to the topic and the time frame between 2007 and 2023. This meticulous process reduced the selection to 192 papers, which allowed for a focused database and a pertinent analysis.

During PRISMA's elegibility assessement test, the 192 papers were closely analyzed to assess their relevancy in wastewater treatment. This analyisis impleid a deep review of the abstracts and titles, focusing on innovating techniques for treatment, environmental viability, and efficacy. Duplicates were discarded as well as those that digressed from the main objectives of the study, resulting in 93 articles that met the contemporary, relevancy and quality standard for the research.

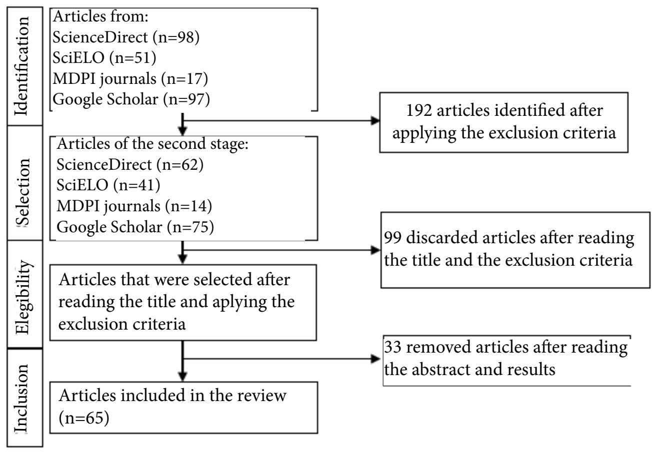

Figure 1. PISMA methodology applied to the review.

In the last stage of the PRISMA methodology applied to the study of wastewater treatments, a detailed synthesis and analysis of the final 65 articles was carried out. This process involved a close examination of each document, identifying key trends, patterns and advances in the field. Through this analysis, a deep and up-to-date understanding of wastewater treatment was obtained, highlighting both the state of the art and future directions for research. This phase contributed considerable value to the body of knowledge in this area, illuminating critical and potential aspects of the technologies involved.

e-ISSN 2477-8982

Results and discussion

Literature review

The evolution of publications regarding wastewater treatment shows a field of study in which interest has fluctuated, but has also been progressive in the scientific community. The year 2016 was the most productive year, with a totoal of 9 articles. This high incidence was followed by seven articles in 2018, which suggests a continued interest and research in the field. Nonetheless, two years, 2017 and 2020 saw a decrease in scientific production with only two articles, while 2012 and 2015 saw four articles each. Recently, the year 2023 has met 2016 numbers with another nine articles, which evidenced a resurgance and sustained dedication to the research in the field. The years 2021 and 2022 also reflected continued attention with four and articles, respectively. This pattern underlines the importance and constant interest in the improvement of wastewater treatments, showing it to be a field of active research and expansion.

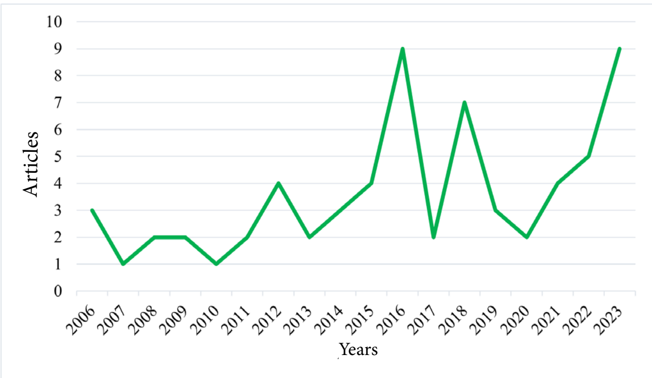

Figure 2. Scientific production throughout the years

Wastewater treatment methods

It refers to a set of activites that aim to treat polluted waters, which may have been produced by residential or industrial environment as a result of their operations. The treatment process encompasses a series of processes and mechanisms designed to purify water that has been polluted from chemical or industrial activities (Morató et al., 2006). The main objective is to reuse and recycle the water, either reintroducing it to the environment or channelling into the sewer systems. It is fundamental to carry out an evaluation and exhaustive analysis of the waters before starting the pre-treatment process, to define the specific strategies that are required (UNESCO, 2018). Wastewater treatments are classified according to their nature and the technology (figure 3).

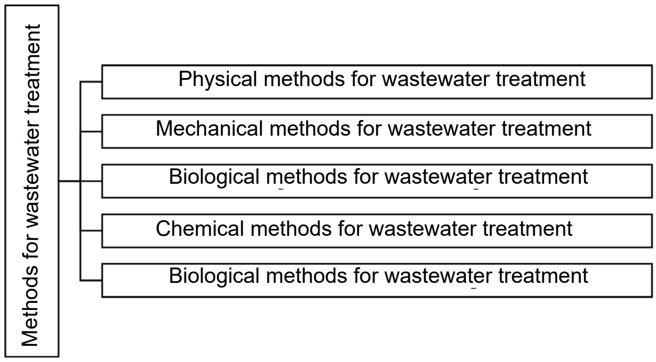

Figure 3. Types of wastewater treatments.

Physical methods for wastewater treatment

Sedimentation

It is the physical process in which suspended particles of a higher density than that of the fluid that contains them, are deposited due to gravity. This process depends on the properties of the particles, such as size, shape and density, as well as fluid properties like viscosity and density. Sedimentation is commonly used for industrial and urban wastewater treatments to remove settleable solids before biological treatment. The treatment was done on tanks or clarifiers where the velocity of the fluid was reduced to allow for decantation of the particles due to the different densities between the fluid and the particles. The settled material gathered at the bottom and was periodically removed as sludge.

In table 1, Ghanem et al. (2010) analyzed the velocity of sedimentation of flocs from chemical coagulants, ballast of different sizes of micro-sand through column tests. Solís et al. (2013) proposed and tested the sedimentation for 24 hours as a low cost pre-treatment to decrease the chemical demand of oxygen (CDO) and the color of textile effluents in laundries. On the other hand, Oliva et al. (2008) developed an optical system to measure the velocity of sludge sedimentation and compare it to the graduated cylinder method. Finally, Arguedas-Zumbado et al. (2016) analyzed an industrial settler, for which they identified a low performance and therefore proposed remodelling it to meet the discharge norms.

Table 1. Wastewater studies that used sedimentation methods.

Settled waste	Location of study		Author
Flocs ballast with microsand	Venezuela	Sedimentation velocity as a function of dosage and grain size of the ballast agent. Velocity ranges from 145 to 225 $m \cdot h^{-1}$	(Ghanem et al., 2010)
Textile wastewater sludge	México	Sedimentation for 24 hours as a pretreatment. COD removal from 35 to 67%. Visible color removal. Phytotoxicity of pretreated water.	(Solís et al., 2013)
Wastewater sludge	Yucatán, México	Sedimentation rate measured with an optical system and graduated cylinder. Zonal sludge sedimentation. Sedimented sludge layer.	(Oliva et al., 2008)
Industrial wastewater sludge	Costa Rica	Total suspended solids (TSS) concentration at the inlet and outlet of the sedimentation tank. Retention time. TSS removal efficiency of the system.	(Arguedas-Zumbado et al., 2016)

The study by Ghanem et al. (2010) showed that the sedimentation velocity grew alongside the ballast agent dosage, on a linear relationship, but with no clear trend with regards to the size of the microsand. On the other hand, Oliva et al. (2008) showed that their optical system provided more accuracy compared to conventional methods. These findings highlight the relevancy of advanced techniques for measuring and controlling sedimantion processes, which suggests significant progress towards more efficient and accurate wastewater treatments.

The study from Arguedas-Zumbado et al. (2016) showed significant improvement in the concentration of total settled solids after remodelling the settler, with a decrease between 296 and 40 $mg \cdot L^{-1}$, placing it under the sllowed limit of 50 $mg \cdot L^{-1}$. On the other hand, Solís et al. (2013) reported an efficient decrease of CDO in the textile effluents, reaching 70% of the sedimentation proces. These specifici data showed the efficacy of the improvements on the sedimentation processes and the positive impact on the quality of the treated water.

Aeration

This activated sludge process consist of pumping air into a tank, which fosters microbial growth in the wastewaster. The microbes feed on organic matter and form flocks that settle easily. After settling on a separate sedimentation tank, the bacteria that form the "activated sludge" continously recirculate bacj to the aeration tank to increase the decomposition velocity (figure 4). The most common desgins use conventional stirred tank reactors, aeration in stages and continous flow (Ahammad et al., 2016). For industrial use, the most common aeration method was aeration through water fall, using spray nozzles. The aeration through air diffusion was also tested, in which the air was diffused in a container with water flowing counter-current (Teixeira et al., 2013).

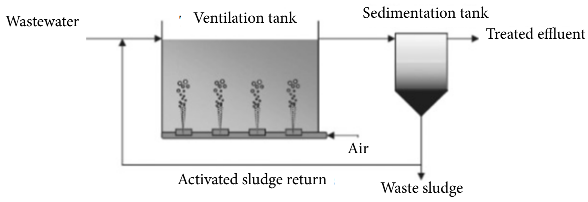

Figure 4. Activated sludge processes.

Source: Ahammad y Sreekrishnan (2016).

Authors such as Teixeira et al. (2013) and Uggetti et al. (2016) tested the efficiency pf phosphorus removal in wastewater, the former on three-phase fluidized bed reactors and the latter on constructed subsurface flow wetlands (table 2). Both studies analyzed parameters such as initial and final concentration, removal efficiency, and the impact of factors like water retention time and average support concentration. Teixeira et al. (2013) obtain total phosphorus removal time values of 32.7% with short retention time (0.19 hours), while Uggetti et al. (2016) reached 38.4% reactive phosphorus removal with longer times (3 hours). Although the processes differed, the results show biological processes' potential for phosphorus removal if carried out under controlled situations.

Mechanical methods for wastewater treatment

Ceramic membranes have significant advantages for separation Their separation functions are based on the "sifting" theory, Su función de separación se basa en la teoría del "cribado". For permeable substances of varying permeability, the different in pressures was used as a driving force to allow small molecular substances to pass through and intercept bigger molecular substances to achieve separation (Zhang et al., 2023).

e-ISSN 2477-8982

Table 2. Studies about wastewater treatment using the aeration method.

Residue	Location	Parameters	Autor
Phosphorus	Brazil	Reactive phosphorus removal efficiency and total phosphorus in aerobic three-phase fluidized bed reactors	(Teixeira et al., 2013)
Phosphorus	Spain	Reactive phosphorus removal efficiency by intermittent aeration in horizontal subsurface flow constructed wetlands	(Uggetti et al., 2016)

These membranes are made with inorganic materials like alumina, silicon carbide, titanium oxide and zeolites, which provides them with desirable properties for wastewater treatments, for example, high chemical stability, resistance to high temperatures, high mechanical resistance, and long lifespans. Moreover, they were capable of resisting agressive chemical environments and severe working conditions that polymeric membranes could not withstand (Lin et al., 2018).

According to Qiu et al. (2018), ceramic membranes are classified according to the size of their pores (table 3), which determines their capacity to separate different contaminants. For example, microfilter membranes were able to retain bacteria and large particles, while inverse osmosis membranes can retain ions and small molecules.

Table 3. Membrane classification according to pore size.

Type of membranes	Pore size
Microfiltration (MF)	0.1 a 10 micrometers
Ultrafiltration (UF)	0.01 a 0.1 micrometers
Nanofiltration (NF)	1 a 10 nanómeters
Reverse osmosis (RO)	0.1 a 1 nanómeters

Source: Qiu et al. (2018).

Table 4 shows three studies that analyzed the use of membranes for wastewater treatment in different industries. Ayala et al. (2006) reached an efficiency level higher than 97% for acid yellow dye removal through nanofiltration, highlighting the efficacy of this technique for specific compounds in the textile industry. By contrast, Salazar et al. (2009) showed that the membrane bioreactor surpassed the activated sludge system, wiht a removal range of CDO between 82-92% and 95% for suspended solids, highlighting the higher efficiency for removing organic contaminants and particles. On the other hand, Escobar-Jiménez et al. (2012) obtained the best results for water recyling in the cereal industry using membranes of 15 and 13 kDa, the former being the most efficient in terms of water flow.

Table 4. Studies about wastewater treatment using ceramic membranes.

Type of wastewater	Waste to be removed	Country	Operatin parameters and membrane size	Author
Textile	acid yellow coloring 23	Colombia	Nanofiltration membrane NF90SR by FILMETC 2,5” diameter,40” length, spiral configuration. Transmembrane pressure 200 psig. Firing rate 15% on the permeate	(Ayala et al., 2006)
Textile	bright blue colorants and tartrazine	Spain	Pilot biorreactor mebrane plant with ultrafiltration membranes UFS3 y UFS2 y microfiltration polysulfur MFS Filtration mode and washing mode.	(Salazar Gámez et al., 2009)
Cereales	Colorantes azul brillante y tartrazina, DQO y conductividad	Mexico	150 y 15 kDa ceramic membranes, and de 50 y 13 kDa polymeric hollow filter membranes. Transmembrane pressure of 3-5 bar. Flow velocity 2,5-3 $m \cdot s^{-1}$ for polymeric membranes and 3 $m \cdot s^{-1}$ for ceramic membranes.	(Escobar-Jiménez et al., 2012)

The effectiveness of nanofiltration for capturing specific molecules, as in the study by Ayala et al. (2006) demosntrated its usefulness for pharmaceutical or fine chemical waste, as these contexts require highly precise contaminant removal. The capacity of the bioreactor by Salazar et al. (2009) to handle large organic loads positioned it as a promising solution for the food and agriculture industries, wherein effluents are rich in organic matter. In the case of Escobar-Jiménez et al. (2012), the need for an efficiency-quality balance also suggests the need for versatile solutions, such as effluent managements in urban sectors or in areas that recycle

latecnica@utm.edu.ec | Vol. 14, Num. 2 (103-117): July-December, 2024 | DOI: 10.33936/latecnica.v14i2.6467

water, like the agricutltural or beverage industries. These trends showed progress towards specialized technologies adapted to specific sector needs.

Biological method for wastewater treatments

This method used implied using microorganisms to decompose contaminant organic matter, thus reducing the contaminant load effectively before water is released into the environment or recycled. These systems, which can be aerobic, anareobic or anoxic, contain microorganisms like bacteria, fungi, protozoos that metabolize contaminants and transform them into cellular matter, CO2, and other gases (Menéndez et al., 2018). The aerobic processes, such as activated sludge, were very common and flexible, adapting to different types of wastewater and can be efficient in removing matter and nutrients. Even with the diverse designs and operations, they all share critical factors such as biomass, organic load, retention time and environmental conditions that must be optimal for effective treatment. Moreover, the sludge that results from this process must be adequately managed to avoid negative impact on the environment (Vargas et al., 2020).

Table 5 shows studies that centered on domestic wastewater biological treatment, as well as those in bottling plants using reactors with aerobic and anaerobic reactors. Torres et al. (2011) analyzed different activated sludge configurations and biodiscs to treat domestic wastewater in Colombia, and reported CDO removal efficiency levels higher than 80%. Linares et al. (2021) also obtained high CDO efficiency levels (88,73%) in bottleing plant wastewater in Venezuela, using aerobic reactors through sequential loads. Duque-Sarango et al. (2018) treated urban wastewater in Ecuador with aerobic rotary biological contactorsin four stages, reaching a CDO efficiency of 86%. Finally, Sánchez-Balseca et al. (2019) tested a biofilm anaerobic reactor for wastewater denitrification in Ecuador, and reported an efficiency of 97,58% in nitrates. The studies proved the effectiveness of biological processes for wastewater contaminant treatment, either using aerobic reactors to remove organic matter, or anaerobics for denitrification.

As for the treatment parameters, Torres et al. (2011) y Duque-Sarango et al. (2018) used suspended biomass aerobic reactors (activated sludge) and biofilms (biodiscs) respectively, to remove organic matter, while

Table 5. Wastewater studies that used biological methods

Type of wastewater	Contaminant to be removed	Country	Treatmetn parameters	Microorganism and condition	Autor
Domestic wastewater	Organic matter	Colombia	Activated sludge: conventional (TRH 4-8 h), extended (TRH 30-8 h), stablized through contact (TRH total 13.1-2.5 h). Biodiscs (TRH 22-0.8 h)	Heterotrophic Bacteria and aerobe	(Torres et al., 2011)
Bottling plant wastewater	CDO, Coliforms	Venezuela	Sequential Burden Reactors (SBR) operated in aerobic and anaerobic conditions	Heterotrophic and autotrophic bacteria	(Linares et al., 2021)
Urban wastewater	Organic matter	Ecuador	Rotatory biological contactors (RBC) in 4 phases	Aerobic heterotrophic bacteria	(Duque-Sarango et al., 2018)
Domestic	Nitrates	Ecuador	Biofilm reactor	Anaerobic denitrifying bacteria	(Sánchez-Balseca et al., 2019)

Linares et al. (2021) tested both aerobic and anaerobic conditions in reactors to reduce CDO and coliforms in sequential loads. Sánchez-Balseca et al. (2019) were the only ones to use bioflim anaerobic reactors for denitrification. In relation to the microrganisms, they all employed heterotrophic aerobes except for Sánchez-Balseca et al., (2019) which used denitrified anaerobic bacteria.

The heterogeneity of biological treatment shown in the studies on table 6 indicate that the personalization of different contaminant removal was crucial. For example, aerobe systems were ideal for CDO on wastewater with high organic loads, such as industrial wastewater, while the anaerobic processes shown potential for nitrate removal, which was crucial in agricultural zones that were affected by overflow rich in fertilizers. These advances may imply a trend towards specialization in biological treatment to attend the particular needs for decontamination according to the effluent's origin.

Moreover, the biological methods consisted of composting from wastewater, and thus, through a literature review, diverse papers were found related to the topic Torres et al. (2007) carried out an experimental study to evaluate the effect of incorporating support materials and composting amends generated at the wastewater treatment plant of Cañaveralejo, Cali, Colombia (table 6). They used leftovers from wood pruning and shavings as support materials and cachaça and organic residue as amends. On the other hand, Íñiguez et al. (2006) assessed the composting from flesh removals and wastewater from a tannery in Mexico in two stages: one of 239 days on static rottings and another one of 204 days with flios and risk with wastewater. Meanwhile, Vicencio-De La Rosa et al. (2011) produced compost and vermicompost from the sludge produced wastewater treatment plant in Mexico.

Table 6. Wastewater treatment studies using the composting method.

Type of wastewater	Location	Operation parameters	Compost characteristics	Author(s)
PTAR biosolids	Colombia	mix of 72% biosolid, support materials and amend.	Physical and chemical improvement	(Torres et al., 2007)
Solid and liquid waste from Tannery	Mexico	239 days on static rotting without flip, 204 days with weekly flips and wastewater risk	Maximum temperature of65 °C. High saline content in the final product	(Íñiguez et al., 2006)
Ballast sludge waste	Mexico	150 days composting on static rotting with flips. 210 days of vermicomposting en pilas con volteos. 210 días de vermicomposteo.	10.9 tonnes of compost. 12.5 tonnes of vermicompost. Higher nutritional quality of compost.	(Vicencio-De La Rosa et al., 2011)

Torres et al. (2007) found that adding biosolids, prunning residue and cachaça improved the physical and chemical characteristics of compost, accelerating the thermophilic phase, maintaining higher temperatures and improving C/N relations. The best mix was 72% biosolid, 10% prunning residue y 18% cachaça (table 6). While Íñiguez et al. (2006) employed prolonged periods of static rottings followed by flips, and Vicencio-De La Rosa et al. (2011) employed flips from the start. These difference influenced the results; for example, Íñiguez et al. (2006) obtained compost with high saline content, due to the risk of wastewater during the process. As for the characteristics of the compost, Torres et al. (2007) y Vicencio-De La Rosa et al. (2011) achieved improvements in the compost's physical and chemical properties, while the product by Íñiguez et al. (2006) had limitations in its composition.

These methods showed potential for improving the quality of the soil and sustainable agriculture, while they faced challenges such as high saline content, which required innovative solutions, to evade negative impact on the soil. The adaptation of these processes to the different types of residue and environmental conditions would be curcial to the success and long-term sustainability.

Chemical treatment for wastewater treatment

Neutralization

The neutralization of acidic wastewater is a chemical process that raises the pH of acidic industrial effluents to neutral levels, generally between 6 and 9. This is achieved by the addition of alkaline substances that neutralize acidity (Nazuwatussya et al., 2023). Acidic wastewater are commonly generated in industrial processes such as mining, metal casting, steel production, and others. These waters often contain compounds like sulfuric or hydrochloric acids, as well as dissolved heavy metals, if they are poured directly, they can damage infrastructure, soils and aquatic ecosystems (Arbona et al., 2023).

The most common neutralizing substances are quicklime (CaO), hydrated lime ($Ca(OH)_2$), sodium carbonate (Na_2CO_3), sodium hydroxide (NaOH) and calcium carbonate ($CaCO_3$). When they were added, they reacted with the acids from the wastewater and generated salts and water, increasing the pH. The process was done on neutralization tanks (Lochyński et al., 2021).

Jarnerud et al., (2021) presented an experimental study about the use of waste paste and paper factories, which contained CaO, like flying ashes and calcinated sludge, to neutralize acidic wastewater that resulted from prickling processes in steel production (table 7). On the other hand, Forsido et al. (2019) reported study about the use of slag from electric arc furnaces, combined with lime, to neutralize acid effluents and remove metals from a steel plant. Finally, Zvimba et al. (2017) presented an experimental study of the use of slag from a basic oxygen furnace for passive neutralization of mine acidic drainage.

Table 7. Wastewater studies that used the enutralization method.

Type of wastewater	Location	Neutralizing substances	Operation parameters	Author(s)
Acid pickling agents in steel production	Sweden	Fly ash and calcined sludge from pulp and paper industriesl	Addition of 9.5-52 g L^{-1} of ash or 4-19 g L^{-1} of sludge; agitation at 500 RPM; neutralization time of 30 min	(Jarnerud et al., 2021)
Acid effluents from the steel industry	South Africa	Electric arc furnace slag and lime	Addition of 54 g L^{-1} slag and 0.7 g L^{-1} lime; stirring at 380 RPM; neutralization time 1-96 hours	(Forsido et al., 2019)
Acid mining drainage	South Africa	Basic oxygen furnace slag	Passive neutralization system; neutralization time 1-90 days	(Zvimba et al., 2017)

The operation parameters varied from active agitation process and direct reactive addition, to passive systems with longer retention times. However, a succesful neutralization was achieved in all cases, reaching the desired pH range of 6-p and removing metals through precipitation. In terms of results, although the neutralization kinetics depended on a specific process, all the studies showed that acid and metal removal percentages were higher than 90%. Even the passive process by Zvimba et al. (2017) reached these levels in relatively short periods (10 days).

The study on table 7 showed growth in the use of industrial waste for wastewater treatment, an advance towards environmental sustainability. These studies showed how the subproducts, such as ashes and slag, can be efficiently recycled to correct the the acidity in water, which reduced the need for chemical neutralizers and used materials that would otherwise be discarded. This focus not only offered more ecological treatment solutions, but it also fostered a circular economy aligned with current challenges in waste management and resource conservation.

Adsorption

This is a key technique for acidic wastewater treatment. It uses adsorbent material to eliminate contaminants such as heavy metals and organic compounds. The process is founded on the chemical and physical affinity between adsorbents and contaminants, and its efficiency is dependent on the nature of the adsorbent and environmental conditions. Materials like activated charcoal and zeolites were frequently chosen for their capacity to capture and wide range of contaminants (Jagadeesh et al., 2023). Besides being an efficient method of toxic substance removal, adsorbtion is also valued for its simplicity and potential for meeting strict environmental requirements, which makes it an attractive option compared to traditional methods, specially as a tertiary method for polishing wastewater before it is discharged or recycled (Paccha Rufasto et al., 2023).

After analyzing the relevant literature for adsorption for wastewater, authors such as Tejada-Tovar et al. (2015) have presented an analysis about the use of biological materials as adsorbents for heavy metals in wastewater treatment, Moreover, they they describe the adsorption fundamentals, the biomaterials that are used, their modifications and other factors that influence the adsorption of metallic ions (table 8). On the other hand, García-Rojas et al. (2012) analyzed adsorbtion as a tertiary or polishing method for wastewater, presenting basic concepts, types of adosrpition, a description of the experimental process and modelation using adsorption isotherms. Lastly, Cascaret-Carmenaty et al. (2014) analyzed cromium adsorption (VI) through bacterian biomass, describing strain selection, pH effects, kintetic modelation and appliction on a real wastewater matrix.

Table 8. Wastewater studies that applied the adosrption method.

Wastewater type	Location	Type of absorbent	Operation parameters	Author(s)
Industrial wastewater with heavy metals	Colombia	Tamarind peel, orange peel, banana peel, corn leaves, peanut shell, chitosan, grape stem residue	pH, particle size, temperature, metal concentration	Tejada-Tovar et al. (2015)
Wastewater with heavy metals	México	Biomass	pH, contact time, initial concentration	(García-Rojas et al., 2012)
Galvanized waste water with chromium (VI)	Cuba	Biomass of bacterial strains isolated from galvanic residue	pH, biomass concentration	(Cascaret-Carmenaty et al., 2014)

Tejada-Tovar et al. (2015) presented a wide analysis of biological adsorbents for industrial wastewaters, while García-Rojas et al. (2012) focused on adsorption with biomass. On the other hand, Cascaret-Carmenaty et al. (2014) studied a specific case of bacterian biomass for galvanized wastewaters with chromium (VI). These studies underligned the biomass' potential, from

e-ISSN 2477-8982

agricultural waste to specialized bacterian strains, to remove heavy metals and other toxic compounds (table 9). As for the operational conditions, the three studies agreed on the importance of pH as a key parameter, but differed on other factors such as biomass concentration, contact time, and temperature. It was evidenced that the research on adsorption for wastewater treatment must be optimized according to the type of contaminant and the adsorbent in use.

Precipitation

Chemical compounds were used on wastewater to change the physical state of the suspended and dissolved solids and they were then separated through sedimentation. In quantitative terms, the separation of the solution became more complete, depending on the insolubility of the resulting compound (Barat et al., 2009). Thus, chemical precipitation, in contrast with other chemical methods of wastewater treatment, was considered to be a primary or main purification process, because it allowed to obtain water that is almost free of suspended solids. Moreover, special attention has been paid to the removal of phosphorus and other compounds (Hualpa-Cutipa et al., 2022).

Zhang et al. (2020) They analyzed the preparation of magnesium hydroxycarbonate from low-grade magnesite, and its use as a precipitating agent for heavy metals (VO_2^+, Cr_3^+ and Fe_3^+) in industrial AR. The study succeeded in reducing the concentrations of these metals below the discharge limits in China (table 9). In contrast, Barat et al. (2009) presented a case study on precipitation issues at the Murcia Este wastewater treatment in Spain; a biomass balance analysis was performed to identify the sources of precipitation, finding that it occurs mainly in the anaerobic digesters. While Córdova et al. (2014) compared the chemical precipitation of chromium in effluents from traditional and alternative leather tanning processes; the alternative processes required a lower dose of sodium hydroxide due to the use of chromium complexing agents.

Table 9. Wastewater treatment studies that used the precipitation method.

Wastewater type	Precipitant compound	Precipitated substance	Operation parameters	Author(s)
Tannery wastewater	Synthetic carbonated magnesium hydroxide	VO_2^+, Cr_3^+, Fe_3^+	pH 7.1, 0.3 g L^{-1} $Mg_5(OH)_2(CO_3)_4$, stirring for 20 min at room temperature	(Zhang & Duan 2020)
Urban wastewtaer	Sodium hydroxide	Struvite, hydroxyapatite	pH 7.5 in anaerobic digester, increase in NH_4^+ concentration from 139 to 922 mg L^{-1}, anaerobic digestion with TRS of 38% and organic load of 1.9 gCODL day^{-1}	(Barat et al., 2009)
Traditional and alternative tannery wastewater	Sodium hydroxide	Cr_3^+	Optimum pH between 7.4-10 by adding 0.5-5.5 g L^{-1} of NaOH, stirring at room temperature	(Córdova Bravo et al., 2014)

The studies analyzed obtained high removal efficiencies of the target substances by adjusting the pH between 7.1 and 10, by adding the precipitating compounds in ranges of 0.3 to 5.5 g L^{-1}, during reaction times of 20 min at room temperature, in stirred processes. Further research is required to determine the kinetics of the reactions and evaluate the applicability of these methods on a larger scale. These studies emphasized the relevance of adjusting the pH and precipitant dosage to achieve high removal efficiencies, and suggested that future research should delve deeper into the reaction kinetics and scalability of these solutions.

Disinfection

This is a widely used method, Casierra-Martínez et al. (2016) tested a combination of a solar photocatalytic process with hydrogen peroxide and system of wetlands built for domestic wastewater disinfection and its recycle risk (table 10). On the other hand,Zurita et al. (2015) compared the efficiency of three pilot systems of hybrid wetlands, built in two stages for total coliform and *Escherichia coli* removal in domestic wastewate. On the other hand, Noriega-Treviño et al. (2012) presented a comparative study of the anti-bacterial effectiveness of metallic nanoparticles in waters with different chemical composition, as an alternative for water disinfection, and they proposed the use of composite membranes for inverse osmosis and nanofiltration.

Table 10. Wastewater treatment studies that used the disinfection method.

Wastewater type	Location	Disinfecting compound	Microorganism	Operation parameter	Author(s)
Domestic	Colombia	Solar UV/ $H_2O_2^+$ constructed wetlands	Total and fecal coliforms	5 h in solar photorreactor, 3 days in wetlands. Dosage H_2O_2: 3, 30 and 300 mg·L^{-1}	(Casierra-Martínez et al., 2016)
Domestic	Mexico	Hybrid constructed wetlands	Total coliforms and *Escherichia coli*	1 año de operación, 4 meses de estabilización, 8 meses de monitoreo.	(Zurita Martínez et al., 2015)
Synthetic	México	Nanopartículas metálicas	*E. coli* y *E. faecalis*	CMI y CMB de nanopartículas metálicas. Matrices de agua sintética.	(Noriega-Treviño et al., 2012)

According to the studies that were reviewed, it was observed that Zurita et al. (2015) and Casierra-Martínez et al. (2016) used biological treatment systems (artificial wetlands) for domestic wastewater disinfection and the removal of total coliforms and *E. coli*. removal. Both studies were carried out in latinamerican countries (Colombia and México), which reflected the importance of findinglow-cost methods for wastewater treatments in this region. However, Casierra-Martínez et al. (2016) complemented the biological system with a advanced oxidation stage (solar UV/H_2O_2), achieving high efficiencies on wastewater disinfection, Noriega-Treviño et al. (2012) assessed the application of metallic nanoparticles, specifically silver, as an alternative to water disinfection, demosntrating its effectiveness against *E. coli* and *E. faecalis* in the laboratory. Unlike other studies, this one was executed using synthetic water and measuring parameters such as minimal inhibitory and bactericide concentration. It was found that the smaller silver nanoparticles presented higher antibacterial activity.

Regarding the operation parameters, the hydrolic retention times were higher than those in the biological systems (days or months) in comparison with the requred hours for the solar UV/H_2O_2 system. Moreover, the studies emphasized the relevanyc of adjusting the pH and the dosification of precipitants to reach high removal efficiencies, and the suggest that further research should go more in depth in the reaction kinetics and the scalability of these solutions.

Advanced methods for wastewater treatments

Thanks to technological advances, various uniques treatment methods have been discovered. These are some of the modern wastewater treatments that have been developed.

UV irradiation technology

This is a disinfection method used to inactivate pathogenic microorganisms. This process does not use chemical products, which makes it friendlier to the environment than other disinfection methods like chlorination (Beck et al., 2015). The UV light damages the DNA or RNA of the microorganisms, preventing their reproduction, and thus, their ability to cause disease. This method is effective against a range of pathogens, including bacteria, viruses and protozoos (Song et al., 2016). Moreover, UV treatment is fact-action technique and can be adjusted to handle different contaminant loads, which makes it adequate for its integration on current and future wastewater treatments (Zhang et al., 2019).

The following studies have discussed the UV irradiation methodo; Malato et al. (2016) studied water decontamination and disinfection through solar photocatalysis, using titanium dioxide (TiO_2) and experimentation at the Plataforma Solar in Almería. The study focused on the efficiency of the process to remove contaminants and pathogens in water (table 11). On the other hand, González et al. (2023), carried out a wastewater disinfection using UV light and described the microbian reactivation post-treatment. They proposed strategies to improve disinfection efficiency, combining advanced oxidation processes, to achieve a safer and more effective treatment. Finally, Zhang et al. (2017) analyzed the effects of UV disinfection for antibiotic-resistant *E. coli* from wastewater. They assessed how UV disinfection affected the resistance profiles to and the antibiotic resistance genes (ARGs) of these bacteria.

Table 11. Watewater treatment that the UV irradiation method.

Wastewater type	Location	Disinfecting compound	Operation parameters	Author(s)
Wastewater	España	TiO_2/UV	TiO_2 concentration, UV light intensity, water pH	(Malato et al., 2016)
Urban wastewater	Chile	UV	UV light intensity, contact time	(González et al., 2023)
Wastewater	China	UV	UV light intensity, contact time, antibiotic resistance levels	(Zhang et al., 2017)

The reviewed literature showed UV light as a disinfecting agent, the study by González et al. (2023) reported a decrease of 99,9% of *E. coli* populations in urban wastewater, using a dosage of 30 mJ·cm^{-2}. Comparatively, the study by Zhang et al. (2017) highlighted the necessity to increase UV dosage to 60 mJ·cm^{-2} to achieve an inactivation comparable for antibiotic-resistant *E. coli* strains, which suggests a higher threshold for more robusts pathogens. This data highlighted UV's efficiency against microorganisms with different resistance profiles. On the ither hand, the study by Malato et al. (2016) introduced solar photocathalysis with TiO_2, showng organic contaminant degradation up to 80% on pilot tests, and also indicating potential for hydrogen production, not only for sustainable wastewater treatment but also for renewable energy generation.

These results pointed towards a future where water disinfection becomes more sustainable and multi-functional. The trend indicated that UV baseer research d technologies and photocatalysis can be adapted to satisfy specific needs such as resistant pathogen inactivation, and emerging

p-ISSN 1390-6895/e-ISNN 2477-8982 | Vol. 14, Num. 2 (103-117): July-December, 2024 | DOI: 10.33936/latecnica.v14i2.6467

contaminant degradation. Further research could focus on photocatalysis integration with other treatment methods to form hybrid systems that face wastewater treatment challenges.

Conclusion

There is wide variety of wastewater treatment technologies, from the more conventional ones like sedimentation, neutralization, and disinfection, to the more technologically advanced luke membrances, advanced oxidation process and specialized biological treatment The biological methods, such as activated sludge and constructed wetlands, are very effective in removing organic matter. The have shown CDO removal efficiency levels of 80% for domestic wastewater, and 88% for industrial effluents. Meanwhile, the physiochemmical processes, like sedimentation, adsorbtion, and advanced oxidation are useful for removing specific compounds.

The reviewed literature show that there is no unique solution that can be applied to all cases, but that a combination of technologies and hybrid systems is required to achieve an integral treat,ent. The membrane technologies, in particular nanofiltration, ultrafiltration, are emerging as promising alternatives for selective removal of specific contaminants. Likewise, there is an evolution towards sustainable processes, using waste as a resource for treatments, and generating exploitable subproducts or minimizing energy consumption.

Conflict of interest

The authors declare that they have no conflicts of interest in this publication at any stage.

Bibliographic references

Ahammad, S. Z. and Sreekrishnan, T. R. (2016). *Energy from wastewater treatment*. Chapter 20, Elsevier, p. 523-536. https://doi.org/10.1016/B978-0-12-802830-8.00020-4

Arbona Cabrera, M., Cabrera Estrada, I., O'Farril Pie, M. E. y Fabelo Falcón, J. A. (2023). Determinación de la influencia de variables de operación en la neutralización de las aguas residuales textiles con CO_2. *Afinidad. Journal of Chemical Engineering Theoretical and Applied Chemistry*, *80*(599), 187-192. https://doi.org/10.55815/417974

Arguedas-Zumbado, N., Vetrani-Chavarría, K., Murrell-Blanco, M. y Bermúdez-Hidalgo, L. (2016). Propuesta de remodelación del sistema de sedimentación del quebrador de materiales de la empresa CONCREPAL, Barranca, Costa Rica. *Revista de Ciencias Ambientales*, *50*(1), 53-74. https://www.redalyc.org/articulo.oa?id=665070585004

Ayala, M. E., Peñuela Mesa, G. y Montoya, J. L. (2006). Procesos de membranas para el tratamiento de agua residual industrial con altas cargas del colorante amarillo ácido 23. *Revista Facultad de Ingeniería Universidad de Antioquia*, *38*, 53-63. https://www.redalyc.org/articulo.oa?id=43003805

Barat, R., Bouzas, A., Martí, N., Ferrer, J. and Seco, A. (2009). Precipitation assessment in wastewater treatment plants operated for biological nutrient removal: a case study in Murcia, Spain. *Environ Manage*, *90*(2), 850-857. https://doi.org/10.1016/j.jenvman. 2008.02.001

Beck, S. E., Wright, H. B., Hargy, T. M., Larason, T. C. and Linden, K. G. (2015). Action spectra for validation of pathogen disinfection in medium-pressure ultraviolet (UV) systems. *Water Research*, *70*, 27-37. https://doi.org/10.1016/j.watres.2014.11.028

Cascaret-Carmenaty, D. A., Calzado-Lamela, O. y Pérez-Silva, R. M. (2014). Determinación de la capacidad de adsorción de cromo (VI) por biomasa bacteriana. *Revista Cubana de Química*, *XXVI*(3), 215-224. https://www.redalyc.org/articulo.oa?id=443543739005

Casierra-Martínez, H., Casalins-Blanco, J., Vargas-Ramírez, X. y Caselles-Osorio, A. (2016). Desinfección de agua residual doméstica mediante un sistema de tratamiento acoplado con fines de reúso. *Tecnología y Ciencias del Agua*, *VII*(4), 97-111. https://www.redalyc.org/ articulo.oa?id=353549828006

Córdova Bravo, H. M., Vargas Parker, R., Cesare Coral, M. F., Flores del Pino, L. y Visitación Figueroa, L. (2014). Tratamiento de las aguas residuales del proceso de curtido tradicional y alternativo que utiliza acomplejantes de cromo. *Revista de la Sociedad Química del Perú*, *80*(3), 183-191. https://www.redalyc.org/articulo.oa?id=371937639005

Díaz-Cuenca, E., Alavarado-Granados, A. R. y Camacho-Calzada, K. E. (2012). El tratamiento de agua residual doméstica para el desarrollo local sostenible: el caso de la técnica del sistema unitario de tratamiento de aguas, nutrientes y energía (SUTRANE) en San Miguel Almaya, México. *Quivera. Revista de Estudios Territoriales*, *14*(1), 78-97. https://www.redalyc.org/articulo.oa?id=40123894005

Duque-Sarango, P. J., Heras-Naranjo, C., Lojano-Criollo, D. y Viloria, T. (2018). Modelamiento del tratamiento biológico de aguas residuales; estudio en planta piloto de contactores biológicos rotatorios./Modeling of biological wastewater treatment; study in pilot plant of rotating biological contactors. *CIENCIA UNEMI*, *11*(28). https://doi.org/10.29076/issn.2528-7737vol11iss28.2018pp88-96p

Escobar-Jiménez, J., Muro-Urista, C., Esparza-Soto, M., Gómez-Espinoza, R. M., Díaz-Nava, C., García-Gaitán, B., Ortega-Aguilar, R. E. y Zavala-Arce, R. E. (2012).

Recuperación de agua de efluentes de una industria de cereales utilizando membranas. *Tecnología y Ciencias del Agua*, *III*(3), 65-82. https://www.redalyc.org/articulo.oa?id=353531978005

Ewing, T., Babauta, J. T., Atci, E., Tang, N., Orellana, J., Heo, D. and Beyenal, H. (2014). Self-powered wastewater treatment for the enhanced operation of a facultative lagoon. *Journal of Power Sources*, *269*, 284-292. https://doi.org/10.1016/j.jpowsour.2014.06.114

Forsido, T., McCrindle, R., Maree, J. and Mpenyana-Monyatsi, L. (2019). Neutralisation of acid effluent from steel manufacturing industry and removal of metals using an integrated electric arc furnace dust slag/lime process. *SN Applied Sciences*, *1*(12), 1-6. https://doi.org/10.1007/s42452-019-1649-z

García-Rojas, N., Villanueva-Díaz, P., Campos-Medina, E. y Velázquez-Rodríguez, A. (2012). Análisis de la adsorción como método de pulimiento en el tratameinto de aguas residuales. *Quivera. Revista de Estudios Territoriales*, *14*(1), 109-129. https://www.redalyc.org/ articulo.oa?id=40123894007

Ghanem, A., Paulesu, G., Campos, F. y Rodríguez, P. (2010). Comportamiento de la velocidad de sedimentación en flóculos lastrados con diferentes tamaños de microarenas. *SABER. Revista Multidisciplinaria del Consejo de Investigación de la Universidad de Oriente*, *22*(1), 70-79. https://www.redalyc.org/articulo.oa?id=427739443010

González, Y., Gómez, G., Moeller-Chávez, G. E. and Vidal, G. (2023). UV disinfection systems for wastewater treatment: Emphasis on reactivation of microorganisms. *Sustainability*, *15*(14).

Hualpa-Cutipa, E., Acosta, R. A. S., Sangay-Tucto, S., Beingolea, X. G. M., Gutierrez, G. T. and Zabarburú, I. N. (2022). Recent trends for treatment of environmental contaminants in wastewater: An integrated valorization of industrial wastewater. Chapter 15. Elsevier, p. 337-368.https://doi.org/10.1016/B978-0-323-91180-1.00007-7

Íñiguez, G., Rodríguez, R. y Virgen, G. (2006). Compostaje de material de descarne y aguas residuales de la industria de curtiduría. *Revista Internacional de Contaminación Ambiental*, *22*(3), 113-123. https://www.redalyc.org/articulo.oa?id=37022302

Jagadeesh, N. and Sundaram, B. (2023). Adsorption of pollutants from wastewater by biochar: A review. *Journal of Hazardous Materials Advances*, *9*, 1-11. https://doi.org/10.1016/j. hazadv.2022.100226

Jarnerud, T., Karasev, A. V. and Jönsson, P. G. (2021). Neutralization of acidic wastewater from a steel plant by using CaO-Containing waste materials from pulp and paper industries. *Materials (Basel)*, *14*(10), 23-39. https://doi.org/10.3390/ma14102653

Lee, Y.-G. and Chon, K. (2022). Green technologies for sustainable water and wastewater treatment: Removal of organic and inorganic contaminants. *Separations*, *9*(11), 335. https://doi.org/10.3390/separations9110335

Lin, F., Zhang, S., Ma, G., Qiu, L. and Sun, H. (2018). Application of ceramic membrane in water and wastewater treatment. *E3S Web of Conferences*, *53*, 1-4. https://doi.org/10.1051/e3sconf/20185304032

Linares, A., Pire-Sierra, M. G., Lameda-Cuicas, E., Molina-Quintero, L. y Pire-Sierra, M. C. (2021). Tratamiento biológico de aguas residuales generadas en una embotelladora de bebidas no alcohólicas. *Agroindustria, Sociedad y Ambiente*, *1*(8), 89-107. https://revistas.uclave.org/index.php/asa/article/view/3398

Lochyński, P., Wiercik, P., Charazińska, S., & Ostrowski, M. (2021). Research on neutralization of wastewater from pickling and electropolishing processes. *Archives of Environmental Protection*, *47*, 18-29. https://doi.org/10.24425/aep.2021.139499

Malato, S., Maldonado, M. I., Fernández-Ibáñez, P., Oller, I., Polo, I. and Sánchez-Moreno, R. (2016). Decontamination and disinfection of water by solar photocatalysis: The pilot plants of the plataforma solar de Almeria. *Materials Science in Semiconductor Processing*, *42*, 15-23. https://doi.org/10.1016/j.mssp.2015.07.017

Marín Leal, J. C., Chinga Panta, C. A., Velásquez Ferrín, A. I., González Cabo, P. A. y Zambrano Rodríguez, L. M. (2015). Tratamiento de aguas residuales de una industria procesadora de pescado en reactores anaeróbicos discontinuos. *Ciencia e Ingeniería Neogranadina*, *25*(1), 27-42. https://www.redalyc.org/articulo.oa?id=91139263003

Menéndez Gutiérrez, C., y Dueñas Moreno, J. (2018). Los procesos biológicos de tratamiento de aguas residuales desde una visión no convencional. *Ingeniería Hidráulica y Ambiental*, *39*, 97-107. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S1680-03382018000300097

Morató, J., Subirana, A., Gris, A., Carneiro, A. y Pastor, R. (2006). Tecnologías sostenibles para la potabilización y el tratamiento de aguas residuales. *Revista Lasallista de Investigación*, *3*(1), 19-29. https://www.redalyc.org/articulo.oa?id=69530105

Muga, H. E. and Mihelcic, J. R. (2008). Sustainability of wastewater treatment technologies. *Journal of Environmental Management*, *88*(3), 437-447. https://doi.org/10.1016/j. jenvman.2007.03.008

Nazuwatussya, D., Ekawati, E., Pradipta, J. and Yulia, E. (2023). Automation system architecture of pH neutralization process in Batik wastewater treatment plant. *Journal of Physics: Conference Series*, *2673*(1), 012020. https://doi.org/10.1088/1742-6596/2673/1/012020

Noriega-Treviño, M. E., Quintero González, C. C., Guajardo Pacheco, J. M., Morales Sánchez, J. E., Compeán Jasso, M. E. y Ruiz, F. (2012). Desinfección y purificación de agua mediante nanopartículas metálicas y membranas compósitas. *Tecnología y Ciencias del Agua*, *III*, 87-100. https://www.redalyc.org/articulo.oa?id=353531980006

Oliva, J., Vallejos, G., & Pérez, M. (2008). Estudio de la dinámica de sedimentación de lodos mediante un sistema óptico. *Ingeniería*, *12*(2), 17-29. https://www.redalyc.org/ articulo.oa?id=46712202

OMS. (2023). Declaración política de la tercera reunión de alto nivel de la Asamblea General sobre la prevención y el control de las enfermedades no transmisibles, y salud mental. *CONSEJO EJECUTIVO 152.ª reunión. Punto 6 del orden del día provisional*, 1-25. https://apps.who.int/gb/ebwha/pdf_files/EB152/B152_6-sp.pdf

Paccha Rufasto, C. A. y Paccha Huamani, P. R. (2023). Capacidad de adsorción de desechos agroindustriales para remover contaminantes de aguas residuales. *Revista del Instituto de investigación de la Facultad de Minas, Metalurgia y Ciencias Geográficas*, *26*(51), 1-12. https://doi.org/10.15381/iigeo.v26i51.25258

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuinness, L. A., Stewart, L. A., Thomas, J., Tricco, A. C., Welch, V. A., Whiting, P. and Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Systematic Reviews*, *10*(1), 89. https://doi.org/10.1186/s13643-021-01626-4

Peña Barreto, J. A. (2016). Saneamiento ambiental y participación ciudadana. *Revista Scientific*, *1*(1), 53-71. https://www.redalyc.org/articulo.oa?id=563660226005

Peña, S., Mayorga, J. y Montoya, R. (2018). Propuesta de tratamiento de las aguas residuales de la ciudad de Yaguachi (Ecuador). *Ciencia e Ingeniería*, *39*(2), 161-167. https://www. redalyc.org/articulo.oa?id=507557606007

Qiu, Q., Zhao, B. w. and Qiu, L. P. (2018). Development of flat ceramic membrane technology on municipal wastewater treatment. *IOP Conference Series: Materials Science and Engineering*, *392*(2), 2-6. https://doi.org/10.1088/1757-899X/392/2/022036

Rodríguez-Valencia, N., Quintero-Yepes, L. y Castañeda, S. A. (2022). Construya y opere su sistema séptico para el tratamiento de las aguas residuales de la vivienda de su finca cafetera. *Cenicafe*, *12*, 23-40. https://doi.org/10.38141/cenbook-0012

Rodríguez Miranda, J. P., García-Ubaque, C. A. y García-Ubaque, J. C. (2016). Enfermedades transmitidas por el agua y saneamiento básico en Colombia. *Revista de Salud Pública*, *18*(5), 738-745. https://www.redalyc.org/articulo.oa?id=42249785004

Rojas-Morales, J. L., Gutiérrez-González, E. C. y Colina-Andrade, G. d. J. (2016). Obtención y caracterización de carbón activado obtenido de lodos de plantas de tratamiento de agua residual de una industria avícola. *Ingeniería, Investigación y Tecnología*, *17*(4), 453-462. https://doi.org/10.1016/j.riit.2016.11.005

Sáez Huamán, W., Palomino Pastrana, P. A., Dávila Victoria, H. M. y Tito Córdova, L. A. (2022). Aguas residuales en la calidad de agua del río. *GnosisWisdom*, *2*(3), 30-36. https://doi.org/10.54556/gnosiswisdom.v2i3.43

Salazar Gámez, L., Rosell, M. C. y Salazar, R. (2009). Tratamiento de aguas residuales textiles mediante un biorreactor de membrana. *Ingeniería y Desarrollo*, *26*, 83-99. https://www.redalyc.org/articulo.oa?id=85212233007

Sánchez-Balseca, J. J., Muñoz-Rodríguez, I. M. y Aldás-Sandoval, M. B. (2019). Tratamiento biológico de desnitrificación de aguas residuales usando un reactor de biopelícula con cáscara de arroz como fuente de energía. *Tecnología y Ciencias del Agua*, *10*(2), 78-97. https://doi.org/10.24850/j-tyca-2019-02-03

Sánchez Proaño, R. G. y García Gualoto, K. J. (2018). Tratamiento de aguas residuales con cargas industriales con oxidación avanzada en sistemas convencionales. *La Granja. Revista de Ciencias de la Vida*, *27*(1), 103-111. https://www.redalyc.org/articulo.oa?id= 476054842008

Semaha, P., Lei, Z., Yuan, T., Zhang, Z. and Shimizu, K. (2023). Transition of biological wastewater treatment from flocculent activated sludge to granular sludge systems towards circular economy. *Bioresource Technology Reports*, *21*, 101-116. https://doi.org/ 10.1016/j.biteb.2022.101294

Solís, M., Gil, J. L., Solís, A., Pérez, H. I., Manjarrez, N., & Perdomo, M. (2013). El proceso de sedimentación como una aplicación sencilla para reducir contaminantes en efluentes textiles. *Revista Mexicana de Ingeniería Química*, *12*(3), 585-594. https://www.redalyc. org/ articulo.oa?id=62029966020

Song, K., Mohseni, M. and Taghipour, F. (2016). Application of ultraviolet light-emitting diodes (UV-LEDs) for water disinfection: A review. *Water Research*, *94*, 341-349. https://doi. org/10.1016/j.watres.2016.03.003

Teixeira Correia, G., Sánchez Ortiz, I. A., Gebara, D., Dall'Aglio Sobrinho, M. y Matsumoto, T. (2013). Remoción de fósforo de diferentes aguas residuales en reactores aeróbios de lecho fluidizado trifásico con circulación interna. *Revista Facultad de Ingeniería Universidad de Antioquia*, *67*, 172-182. https://www.redalyc.org/articulo.oa?id=43029146015

Tejada-Tovar, C., Villabona-Ortiz, Á. y Garcés-Jaraba, L. (2015). Adsorción de metales pesados en aguas residuales usando materiales de origen biológico. *TecnoLógicas*, *18*, 109-123. http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S0123-77992015000100010

Torres Lozada, P., Vasquez, N., Pérez Vidal, A., Madera, C. y Rodriguez, J. (2011). Alternativas de tratamiento biológico aerobio para el agua residual doméstica del municipio de Cali, Colombia *Afinidad -Barcelona-*, *LXVIII*, 49-55. https://www.raco.cat/index.php/afinidad/article/download/268129/355707

Torres, P., Pérez, A., Escobar, J. C., Uribe, I. E. y Imery, R. (2007). Compostaje de biosólidos de plantas de tratamiento de águas residuales. *Engenharia Agrícola*, *27*. https://www.scielo. br/j/eagri/a/wcTXZFrqkkhXkhS36V9DKGw/#

Uggetti, E., Hughes-Riley, T., Morris, R. H., Newton, M. I., Trabi, C. L., Hawes, P., Puigagut, J. and García, J. (2016). Intermittent aeration to improve wastewater treatment efficiency in pilot-scale constructed wetland. *Science of the Total Environment*, *559*, 212-217. https://doi.org/10.1016/j.scitotenv.2016.03.195

UNESCO, Informe Mundial de las Naciones Unidas sobre el Desarrollo de los Recursos Hídricos 2018. (2018). Soluciones basadas en la naturaleza para la gestión del agua, París. p. 168. https://unesdoc.unesco.org/ark:/48223/pf0000261605_spa

Vargas, A. K. N., Calderón, J., Velásquez, D., Castro, M. y Núñez, D. A. (2020). Análisis de los principales sistemas biológicos de tratamiento de aguas residuales domésticas en Colombia. *Ingeniare. Revista Chilena de Ingeniería*, *28*, 315-322. https://doi.org/10.4067/ S0718-33052020000200315

Velázquez-Chávez, L. D. J., Ortiz-Sánchez, I. A., Chávez-Simental, J. A. y Pámanes-Carrasco, G. A. (2022). Influencia de la contaminación del agua y el suelo en el desarrollo agrícola nacional e internacional. *Revista Especializada en Ciencias Químico-Biológicas*, *25*, e482. https://doi.org/10.22201/fesz.23958723e.2022.482

Vicencio-de La Rosa, M. G., Pérez-López, M. E., Medina-Herrera, E. y Martínez-Prado, M. A. (2011). Producción de composta y vericomposta a partir de los lodos de la planta de tratamiento de aguas residuales de un rastro. *Revista Internacional de Contaminación Ambiental*, *27*(3), 263-270. https://www.redalyc.org/articulo.oa?id=37020226011

Wolf, J., Johnston, R. B., Ambelu, A., Arnold, B. F., Bain, R., Brauer, M. and Brown, J. (2023). Burden of disease attributable to unsafe drinking water, sanitation, and hygiene in domestic settings: a global analysis for selected adverse health outcomes. *Lancet*, *401*(10393), 2060-2071. https://doi.org/10.1016/s0140-6736(23)00458-0

Zhang, C. M., Xu, L. M., Wang, X. C., Zhuang, K. and Liu, Q. Q. (2017). Effects of ultraviolet disinfection on antibiotic-resistant *Escherichia coli* from wastewater: inactivation, antibiotic resistance profiles and antibiotic resistance genes. *J. Appl. Microbiol.*, *123*(1), 295-306. https://doi.org/10.1111/jam.13480

Zhang, Y. and Duan, X. (2020). Chemical precipitation of heavy metals from wastewater by using the synthetical magnesium hydroxy carbonate. *Water Sci. Technol.*, *81*(6), 1130-1136. https://doi.org/10.2166/wst.2020.208

Zhang, Y., Tan, Y., Sun, R. and Zhang, W. (2023). Preparation of ceramic membranes and their application in wastewater and water treatment. *Water*, *15*(19), 123-139. https://doi.org/ 10.3390/w15193344

Zhang, Z., Li, B., Li, N., Sardar, M. F., Song, T., Zhu, C., Lv, X. and Li, H. (2019). Effects of UV disinfection on phenotypes and genotypes of antibiotic-resistant bacteria in secondary effluent from a municipal wastewater treatment plant. *Water Res.*, *157*, 546-554. https://doi.org/10.1016/j.watres.2019.03.079

Zurita Martínez, F., Rojas Bravo, D., Carreón Álvarez, A. y Gutiérrez Lomelí, M. (2015). Desinfección de aguas residuales en tres sistemas de humedales construidos híbridos. *Interciencia*, *40*(6), 409-415. https://www.redalyc.org/articulo.oa?id=33938675008

Zvimba, J., Siyakatshana, N., & Mathye, M. (2017). Passive neutralization of acid mine drainage using basic oxygen furnace slag as neutralization material: Experimental and modelling. *Water Science and Technology*, *75*, 1014-1024. https://doi.org/10.2166/wst.2016.579

Author's contribution statement according to the CRediT classification

Fabiola Maribel Jiménez Tamayo: conceptualization, investigation, formal analysis, original draft writing, writing, review, and editing of the article. **Joana Alexandra Moreno López:** original draft writing of the article, and writing, review, and editing of the article. **Mónica Cecibel Encalada Zumba:** formal analysis, writing, review, and editing of the article. **Evelyn Alejandra Vargas Peralvo:** data curation, formal analysis, and writing, review, and editing of the article.