eVitroKhem. 2023; 2:72
doi: 10.56294/evk202372

REVIEW

Studies and technological advances in the treatment of contaminated water

Estudios y avances tecnológicos en la depuración de aguas contaminadas

Libia Belén Arévalo-Saavedra[1], Carlos Mauricio Lozano-Carranza[1], Andi Lozano-Chung[2]

[1]Universidad César Vallejo, Facultad de Ingeniería y Arquitectura. Tarapoto, Perú.
[2]Universidad Nacional de San Martín, Tarapoto, Perú.

Cite as: Arévalo-Saavedra LB, Lozano-Carranza CM, Lozano-Chung A. Studies and technological advances in the treatment of contaminated water. eVitroKhem. 2023; 2:72. https://doi.org/10.56294/evk202372

Submitted: 07-09-2022 **Revised:** 06-12-2022 **Accepted:** 05-02-2023 **Published:** 06-02-2023

Editor: Prof. Dr. Javier Gonzalez-Argote

Corresponding author: Libia Belén Arévalo-Saavedra

ABSTRACT

The research addressed the environmental problems arising from the generation of leachates in landfills and municipal solid waste dumps, recognising them as highly polluting effluents due to their content of organic and inorganic compounds and heavy metals. National and international background information was reviewed, highlighting studies that applied advanced oxidation processes, such as the Fenton method, and phytoremediation techniques with plant species adapted to different environments. Research by Pellón, López and Espinoza characterised leachates based on climatic factors and waste composition, while Medina et al. optimised the Fenton process, finding differences between rainy and dry seasons. Alcalde et al. evaluated bioremediation as a viable alternative, and Jerez verified the ability of plants to accumulate heavy metals in roots and leaves. Sari et al. and Fasani et al. measured the effectiveness of species such as Echinodorus palaefolius and Chrysopogon zizanioides in reducing pollutants and evapotranspiration. Key parameters such as pH, total suspended solids, chemical and biochemical oxygen demand, and total petroleum hydrocarbons, as defined by the APHA and EPA, were highlighted. Phytoremediation, using species such as Eichhornia crassipes and Pistia stratiotes, proved to be a low-cost, highly efficient alternative capable of removing organic compounds, metals and microorganisms through processes such as phytoextraction, phytodegradation and rhizofiltration. It was concluded that the combination of these techniques with continuous monitoring and proper biomass management constituted a sustainable, technically and economically viable strategy for leachate management, contributing to the protection of water resources and the achievement of environmental objectives.

Keywords: Leachates; Phytoremediation; Eichhornia Crassipes; Pistia Stratiotes; Sustainable Treatment.

RESUMEN

La investigación abordó la problemática ambiental derivada de la generación de lixiviados en rellenos sanitarios y vertederos de residuos sólidos urbanos, reconociéndolos como efluentes altamente contaminantes por su contenido de compuestos orgánicos, inorgánicos y metales pesados. Se revisaron antecedentes nacionales e internacionales, destacando estudios que aplicaron procesos de oxidación avanzada, como el método Fenton, y técnicas de fitorremediación con especies vegetales adaptadas a diversos entornos. Investigaciones de Pellón, López y Espinoza caracterizaron lixiviados en función de factores climáticos y composición de residuos, mientras que Medina et al. optimizaron el proceso Fenton, encontrando diferencias en épocas de lluvia y estiaje. Alcalde et al. evaluaron la biorremediación como alternativa viable, y Jerez comprobó la capacidad de plantas para acumular metales pesados en raíces y hojas. Sari et al. y Fasani et al. midieron la efectividad de especies como Echinodorus palaefolius y Chrysopogon zizanioides en la reducción de contaminantes y en la evotranspiración. Se destacaron parámetros clave como pH, sólidos totales en suspensión, demanda química y bioquímica de oxígeno e hidrocarburos totales de petróleo, definidos por la APHA y la EPA. La fitorremediación, con especies como Eichhornia crassipes y Pistia stratiotes, demostró ser una alternativa de bajo costo y alta eficiencia, capaz de eliminar compuestos orgánicos, metales y microorganismos mediante procesos como fitoextracción, fitodegradación y rizofiltración. Se concluyó que la combinación de estas técnicas con monitoreo continuo y manejo adecuado de biomasa constituía una estrategia sostenible, técnica y económicamente viable para la gestión de lixiviados, contribuyendo a la protección de los recursos hídricos y al cumplimiento de objetivos ambientales.

Palabras clave: Lixiviados; Fitorremediación; Eichhornia Crassipes; Pistia Stratiotes; Tratamiento Sostenible.

INTRODUCTION

The environmental problems associated with the generation of leachate in landfills and municipal solid waste dumps represent a growing challenge for the sustainable management of natural resources. These liquid effluents, resulting from water infiltration through the waste mass, contain a complex mixture of organic and inorganic compounds, as well as heavy metals, whose concentration and composition depend on multiple factors: the nature and age of the waste, compaction, climatic conditions, humidity, and precipitation. The presence of these contaminants poses significant risks to ecosystems and human health by compromising the quality of surface and groundwater.

In this context, the scientific literature has developed a large body of research aimed at characterizing leachates and implementing effective treatments for their mitigation. Studies such as those by Pellón et al.[(1)], Medina et al., Alcalde et al., Jerez[(2)], Sari et al., and Fasani[(3)] demonstrate the diversity of methodologies applied, which include advanced oxidation processes—such as the Fenton method—and bioremediation and phytoremediation techniques with different plant species. These approaches are based on the analysis of key parameters, such as pH, total suspended solids, chemical oxygen demand (COD), biochemical oxygen demand (BOD), and total petroleum hydrocarbons (TPH), which allow the magnitude of the impact to be assessed and the viability of each treatment technology to be determined.

Phytoremediation, in particular, has attracted growing interest due to its low cost, ease of implementation, and environmental compatibility. Species such as Eichhornia crassipes (water hyacinth) and Pistia stratiotes (water lettuce) have demonstrated a high capacity to remove contaminants and adapt to diverse environments, making them ideal candidates for projects to restore affected water bodies. These plants use physiological and biochemical mechanisms—such as phytoextraction, phytodegradation, and rhizofiltration—to capture, degrade, or immobilize pollutants, thereby reducing their environmental impact.

Therefore, this study aims to analyze previous studies, theories, and technical parameters that support the use of clean technologies for leachate treatment, with the goal of providing a solid foundation for future research and real-world application projects.

DEVELOPMENT

This research work was based on various international and national references, such as Pellón et al.[(1)], who, in their research entitled "Proposal for the treatment of leachate in a municipal solid waste landfill," aimed to characterize leachate and estimate its generation in a landfill in Havana (city). They based their work on the population and the amount of solid waste generated per day, and also considered a treatment proposal based on their results, thus ensuring that the established standards are met. Their results showed that the characteristics of leachates are highly variable, which is attributed to the interaction of various factors such as the composition and age of the waste, humidity, and precipitation rates, among others. They concluded that leachates are characterized by a high content of mainly organic compounds.[(4)]

Similarly, Medina et al., in their research entitled "Optimization of the Fenton process in the treatment of landfill leachate," treated landfill leachate using the Fenton process, which they describe as an advanced oxidation process that does not require the control of high pressures or temperatures. The study was carried out at a landfill located in Huancayo, Throughout the process, they observed significant differences in the physical and chemical characteristics during the two periods chosen for their study (rainy and dry seasons). During the low water period, they observed higher concentrations of contaminants compared to the rainy seasons, reflecting the significant influence of the environmental conditions of the site and the nature of the waste disposed there. They concluded that the biological degradation index of the leachate improved significantly in both periods, but found that better biodegradable characteristics would be obtained in the leachate.[(5)]

For their part, the research "Characterization of leachate as an alternative that contributes to the mitigation of pollutants," where the objective was to characterize the composition of leachates from household organic waste to propose an alternative that contributes to the reduction of these pollutants. To this end, they carried out a physical-chemical characterization of the leachate by collecting samples from the study site. Taking into account the results obtained from an analysis, they concluded that the implementation of bioremediation processes for the elimination of pollutants is possible as an option for adapting it to a wastewater system.

On the other hand, Jerez[2], in his research aimed at estimating the use of phytoremediation to reduce the increase of heavy metals in leachates, determined the disposition of a leachate taken from a landfill located in Alajuela and established its heavy metal content. The main results were that, in terms of chromium, 20,9 % was found in the aerial part of the plant, while 79,1 % was found in the root. In terms of lead, 5,8 % was found in the root and 94,2 % in the aerial part.

Similarly, Sari et al., in their research entitled "The Effectiveness of Filter Media and Echinodorus palaefolius on Phytoremediation of Leachate," where they determined the effectiveness of the filter media of the plant used for phytoremediation of leachates, was the main objective, using an experimental method with a completely randomized design consisting of several repetitions, specifically four, where the parameters evaluated were turbidity, temperature, total suspended solids, pH, and oxygen. The results obtained were analyzed by an analysis of variance and an additional analysis, showing a significant effect of the filter medium with Echinodorus palaefolius in the phytoremediation of leachate to mitigate the levels of contamination it produces.

In addition, Fasani[3], in their similar research entitled "Phytoremediatory efficiency of Chrysopogon zizanioides in the treatment of landfill leachate: a case study," mentioned that the main objective was to measure the accumulation and tolerance potential of this species and its evapotranspiration capacity in a pot experiment to evaluate its applicability for the containment of leaks from two urban landfill leachates of different composition and the respective treatment of collection ponds. It was found that the leachate samples are compatible with those observed for mature municipal landfills, due to their low pH and organic matter levels; however, highly toxic elements were not detected thanks to the large volume of metals collected. In conclusion, the efficiency of this plant in removing water by evapotranspiration and its tolerance to metals was confirmed.

Additionally, this research project was supported by theories related to leachates, which define them as "fluids that seep into land where landfill or dump facilities are located, carrying dissolved organic and inorganic matter with them. Unfortunately, areas surrounding lakes, rivers, and aquifers are used as municipal, industrial, and commercial solid waste dumps, overflowing their normal buffer level and creating a constant threat to both the environment and the people who may use the water. These leachates have an environmental impact, which remains inactive in the social environment due to the various diseases that can be caused by the different contaminants they contain and, by default, accumulate toxic substances, even increasing mortality. Therefore, they must be treated properly, as numerous reports describe the negative impact they cause", emphasizing that landfill leachates containing heavy metals are significant pollutants and a matter of great concern due to the impact they could have on ecosystems.[6]

"The generation of leachate is caused by various factors: the level of compaction of the waste and the initial moisture content of the garbage, precipitation, evapotranspiration, atmospheric humidity, temperature, infiltration, runoff, and the capacity of the landfill".[7] Landfills remain the most widely used method of solid waste disposal worldwide; leachate generated from landfills creates environmental risks mainly in surface and groundwater, with its high pollutant content, generally has a significant abundance of total organic carbon and a high chemical oxygen demand, as well as a high variation of inorganic and organic contaminants; the treatment of leachate from a landfill or dump is based on processes that seek to remove a significant portion of the contaminants prior to final disposal. Determining the appropriate treatment for this substance is complex, as it involves the concentration of liquid waste with high levels of both organic and inorganic matter, as well as high chemical variation, complicating the selection of an appropriate treatment methodology. Thus, selecting the appropriate treatment requires knowledge of the chemical and physical parameters that characterize them.[7]

Accordingly, general parameters such as pH, which is used as a measure of the alkalinity or acidity of substances, will be applied, as it is necessary to obtain specific results. Total suspended solids are also part of this group, which are defined as solid matter that is dissolved or suspended in a liquid, in this case the leachate generated in a landfill. Organic parameters such as chemical oxygen demand will also be considered. According to the American Public Health Association, this is the "amount of oxygen required to enable organic matter to oxidize in residual water samples under specified conditions of oxidizing agent, time, and temperature." and "Biochemical oxygen demand (BOD) is an analysis used to determine the oxygen requirements for the chemical biodegradation of organic matter in industrial, wastewater, and municipal waters in general." Finally, there are Total Petroleum Hydrocarbons (TPH), which "are a mixture of chemical compounds consisting mainly of carbon and hydrogen, called hydrocarbons, which make up 50 % to 98 % of the composition, originating from crude oil. Since there are several chemical products in crude oil and others that are derived from it, measuring each one separately is not the best approach. However, it is preferable to measure the total portion of hydrocarbons at a site". These parameters are established under the guidelines of the American Public Health Association (APHA) and the Environmental Protection Agency (EPA).

According to Padmavathiamma and Li, one of the characteristics of today's society is the increase in the emission of pollutants into the environment, especially those from mining, domestic, industrial, and agricultural activities, which pose a danger to living beings. As a result, a series of methods are being developed to remedy the impacts they cause.[8,9,10]

Traditional methods can be costly and permanently alter the natural composition of water, soil, and the living beings that inhabit them. For this reason, rising costs and the limited effectiveness of physical-chemical treatments have prompted the creation of different technologies. Phytoremediation can be used to clean up metals, pesticides, solvents, explosives, crude oil, polycyclic aromatic hydrocarbons, and landfill leachate, which refers to a sustainable and low-cost alternative for the recovery of environments that have been altered by natural and anthropogenic contaminants. These technologies are based on the use of plants and microorganisms, which are made more effective through genetic manipulation, improving their remediation capacity.[11,12,13]

For this research, technologies are essential for treatment over large areas, and long-term recovery processes must be considered. This set of technologies offers a number of advantages, mainly in terms of economy and cleanliness; no hazardous reagents of any kind are used that alter the environment in a negative way.[14]

According to Reichenauer and Germida, "For the phytoremediation of contaminants, the following particularities must be taken into account: processes that lead to the complete degradation of contaminants (mineralization), their metabolism inside and outside the plant (rhizosphere), and the absorption of contaminants." These phytotechnologies are based on physiological elements found in plants and microorganisms, such as photosynthesis, transpiration, nutrition, and metabolism. Therefore, phytovolatilization through the leaves, rhizofiltration,[15,16] where the roots are used to adsorb and absorb, and phytomobilization, which is the accumulation in the rhizosphere, can be used as a means of containment. In the case of elimination, phytoextraction, which has the capacity for hyperaccumulation, and phytodegradation itself are used. This will depend on the type of contaminant and the conditions in which it is found.[15,16,17]

Pistia stratiotes and Eichhornia crassipes are species capable of purifying natural components contaminated by various agents. Water hyacinth (Eichhornia crassipes) is a macrophytic plant with submersible, fibrous roots that adapt to different climates, with bluish and lilac flowers. It grows rapidly and a single plant is capable of reproducing more than 60 000 daughter plants, which can grow to between 0,5 and 1,5 meters in height. It is one of the fastest-growing plants in the world, which allows it to spread and adapt to many locations."[19,20]

Purifying action

Water hyacinths can remove certain organic compounds, such as phenol, formic acid, dyes, and pesticides, and reduce the content of BOD, COD, and suspended solids.[20] A reduction in bacteria in wastewater was also observed, which can make the biomass a source of contamination, in which case careful collection is required.[20] "Water lettuce (Pistia stratiotes) is a floating vascular aquatic plant, similar to the floating open head of cabbage (hence the common name), commonly known as water lettuce (lechuguin), native to South America. Its habitats are lakes, rivers, swamps, canals, and rice paddies, and it sometimes grows in water gardens, fountains, and artificial ponds. It has thick, light green, hairy, furrowed leaves and a large number of rosette-shaped aerenkimes (stomata). They have many fibrous, light, feathery roots, and these plants reach a height of 5 cm to 20 cm and a diameter of 6 to 20 centimeters.[20]

Studies have been conducted on the absorption and influence of toxic substances with different concentrations of heavy metals, such as Cr, Cd, and Cu. The biochemical variables are the same (enzymatic activity and RNA, protein, amino acids, and sugars).[2,11,12,21]

CONCLUSIONS

A thorough review of the background and theoretical frameworks allows us to conclude that leachate management is a technical and environmental challenge that requires a comprehensive and multidisciplinary approach. The heterogeneity in the composition of these effluents and the variability of their physicochemical parameters make it difficult to standardize treatments, forcing consideration of the specific conditions of each site, the nature of the waste, and the climatic factors that influence its generation.

Although conventional treatment methods offer satisfactory results in certain circumstances, their high cost and potential negative impact on the environment have prompted the search for sustainable alternatives. In this regard, phytoremediation appears to be a promising strategy, capable of reducing concentrations of organic matter, heavy metals, and other hazardous compounds through natural processes, without the use of aggressive chemical reagents. The species Eichhornia crassipes and Pistia stratiotes, due to their morphological and physiological characteristics, have shown remarkable purification efficiency, confirmed by various experimental studies.

The integration of these techniques with continuous monitoring of parameters such as pH, COD, BOD, suspended solids, and HTP, as well as the implementation of biomass management plans, can ensure not only compliance with environmental regulations but also the preservation of water quality and the reduction of health risks for communities.

In short, the results of this review reaffirm that the treatment of leachate using clean technologies is a viable and necessary way to move towards a waste management model that combines technical efficiency, environmental sustainability, and economic viability, thus contributing to the achievement of sustainable development goals and the protection of water resources for future generations.

BIBLIOGRAPHICAL REFERENCES

1. Pellón A, López M, Espinosa M, González O. Propuesta para tratamiento de lixiviados en un vertedero de residuos sólidos urbanos. Rev Ing Hidrául Ambient. 2015;36(2):3-16. Disponible en: http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S1680-03382015000200001

2. Jerez J. Remoción de metales pesados en lixiviados mediante fitorremediación [tesis de grado]. Costa Rica: Universidad de Costa Rica; 2013. Disponible en: http://www.ciencias.ucr.ac.cr/sites/default/files/Jos%C3%A9%20Jerez-2013-Remoci%C3%B3n%20de%20metales%20pesados%20en%20lixiviados%20mediante%20fitorremediaci%C3%B3n.pdf

3. Fasani E. Phytoremediatory efficiency of Chrysopogon zizanioides in the treatment of landfill leachate: a case study. Environ Sci Pollut Res. 2018;1(1). Disponible en: https://vetiver.org/ITA_Leachate%20Italian.pdf

4. Valderrama C, et al. Optimización del proceso frentón en el tratamiento de lixiviados de rellenos sanitarios. Rev Soc Quím Perú. 2016;82(4):43-7. Disponible en: http://www.scielo.org.pe/scielo.php?script=sci_arttext&pid=S1810-634X2016000400007

5. Torrez V, et al. Caracterización de lixiviados como alternativa que contribuya a la mitigación de contaminantes. Rev ION. 2018;31(1). Disponible en: http://www.scielo.org.co/pdf/rion/v31n1/0120-100X-rion-31-01-59.pdf

6. Espinoza MC, et al. Análisis del comportamiento de los lixiviados generados en un vertedero de residuos sólidos municipales en La Habana.

7. Méndez. Comparación de cuatro tratamientos fisicoquímicos de lixiviados. Rev Int Contam Ambient. 2009;25(3). Disponible en: http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S0188-49992009000300002

8. Tuset S. Tratamiento de lixiviados de vertederos. Tratamiento de aguas residuales, efluentes y aire al servicio del medio ambiente. 2017;1(1). Disponible en: https://blog.condorchem.com/tratamiento-de-lixiviados-de-vertedero/

9. Becerra C. Inauguración de planta de valorización de residuos sólidos en Tarapoto. Andina. Lima: Agencia Peruana de Noticias; 2019;1(1). Disponible en: https://andina.pe/agencia/noticia-san-martin-inauguran-planta-valorizacion-residuos-solidos-tarapoto-754813.aspx

10. Delgadillo A, et al. Fitorremediación: una alternativa para eliminar la contaminación. Rev Int Contam Ambient. 2011;14(2):12-4. Disponible en: http://www.scielo.org.mx/scielo.php?pid=S1870-04622011000200002&script=sci_arttext

11. Madera C, et al. Efecto de la concentración de metales pesados en la respuesta fisiológica y capacidad de acumulación de metales de tres especies vegetales tropicales empleadas en la fitorremediación de lixiviados. Ing Competitividad. 2014;16(2):179-88. Disponible en: http://www.scielo.org.co/pdf/inco/v16n2/v16n2a16.pdf

12. Diez J. Fitocorrección de suelos contaminados con metales pesados: evaluación de plantas tolerantes y optimización del proceso mediante prácticas agronómicas [tesis doctoral]. Santiago de Compostela (ES): Universidad de Santiago de Compostela, Facultad de Biología; 2008. Disponible en: https://minerva.usc.es/xmlui/bitstream/handle/10347/2540/9788498872026_content.pdf?sequence=1&isAllowed=y

13. Organización de las Naciones Unidas (ONU). Medio Ambiente. Perspectiva de la gestión de residuos en

América Latina y el Caribe. 1ª ed. Panamá: Shutterstock.com; 2018. Disponible en: https://wedocs.unep.org/bitstream/handle/20.500.11822/26448/Residuos_LAC_ES.pdf?sequence=1&isAllowed=y

14. Saenz J. Manejo de residuos sólidos en América Latina y el Caribe. Rev Omnia. 2014;20(3):123-5. Disponible en: https://www.redalyc.org/pdf/737/73737091009.pdf

15. CRQ. Especie. En: Glosario de términos ambientales. Oficina de Comunicaciones. p.17. Disponible en: https://www.crq.gov.co/Documentos/GLOSARIO%20AMBIENTAL/GLOSARIO%20AMBIENTAL.pdf

16. Púa A, et al. Análisis de nutrientes de la raíz de la malanga en el trópico seco de Colombia. Rev Chil Nutr. 2019;30(4). Disponible en: https://scielo.conicyt.cl/scielo.php?script=sci_arttext&pid=S0718-07642019000400069

17. Rev Int Contam Ambient. 2010;26(4). Disponible en: http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S0188-49992010000400006

18. Hernández R, et al. Metodología de la investigación. 6ª ed. México: Interamericana Editores; 2014. ISBN: 9786071502919.

19. Pinaffi JV, et al. Seasonal performance of aquatic macrophytes in improving physicochemical parameters of swine wastewater. Rev Bras Biol. 2019. Disponible en: https://www.scielo.br/scielo.php?script=sci_arttext&pid=S1519-69842019005020104&lang=es

20. Rezania S, et al. The efficient role of aquatic plant (water hyacinth) in treating domestic wastewater in continuous system. Int J Phytoremediation. 2016;18(7). Disponible en: https://www.researchgate.net/publication/287286161_The_Efficient_Role_of_Aquatic_Plant_Water_Hyacinth_in_Treating_Domestic_Wastewater_in_Continuous_System

21. Obeidat M. Impact of a domestic wastewater treatment plant on groundwater pollution, north Jordan. Rev Mex Cienc Geol. 2013;30(2). Disponible en: http://www.scielo.org.mx/pdf/rmcg/v30n2/v30n2a9.pdf

FUNDING
None.

CONFLICT OF INTEREST
None.

AUTHOR CONTRIBUTION
Conceptualization: Libia Belén Arévalo-Saavedra, Carlos Mauricio Lozano-Carranza, Andi Lozano-Chung.
Data curation: Libia Belén Arévalo-Saavedra, Carlos Mauricio Lozano-Carranza, Andi Lozano-Chung.
Formal analysis: Libia Belén Arévalo-Saavedra, Carlos Mauricio Lozano-Carranza, Andi Lozano-Chung.
Research: Libia Belén Arévalo-Saavedra, Carlos Mauricio Lozano-Carranza, Andi Lozano-Chung.
Methodology: Libia Belén Arévalo-Saavedra, Carlos Mauricio Lozano-Carranza, Andi Lozano-Chung.
Project management: Libia Belén Arévalo-Saavedra, Carlos Mauricio Lozano-Carranza, Andi Lozano-Chung.
Resources: Libia Belén Arévalo-Saavedra, Carlos Mauricio Lozano-Carranza, Andi Lozano-Chung.
Software: Libia Belén Arévalo-Saavedra, Carlos Mauricio Lozano-Carranza, Andi Lozano-Chung.
Supervision: Libia Belén Arévalo-Saavedra, Carlos Mauricio Lozano-Carranza, Andi Lozano-Chung.
Validation: Libia Belén Arévalo-Saavedra, Carlos Mauricio Lozano-Carranza, Andi Lozano-Chung.
Visualization: Libia Belén Arévalo-Saavedra, Carlos Mauricio Lozano-Carranza, Andi Lozano-Chung.
Writing - original draft: Libia Belén Arévalo-Saavedra, Carlos Mauricio Lozano-Carranza, Andi Lozano-Chung.
Writing - review and editing: Libia Belén Arévalo-Saavedra, Carlos Mauricio Lozano-Carranza, Andi Lozano-Chung.