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ORIGINAL

Phytoremediation efficiency of Pistia stratiotes and Eichhornia crassipes in leachates generated at the Cuñumbuqui landfill

Eficiencia de Fitorremediación de Pistia stratiotes y Eichhornia crassipes en lixiviados generados en el botadero de Cuñumbuqui

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ABSTRACT

The present investigation entitled "Eficiencia de fitorremediación de Pistia stratiotes y Eichornia crassipes en lixiviados generados en el botadero de Cuñumbuqui, San Martín 2020." It has as a general objective is to evaluate the efficiency of the phytoremediation of the selected species that are the Pistia stratiotes and Eichornia crassipes, this research is of an applied type since in the treatment, phytoremediation techniques were applied using macrophyte species under ex situ conditions; with a quasi - experimental design. The population corresponded to the leachate generated in the Cuñumbuqui dump, from which a sample of 130L was obtained, where 20L was distributed for each of the 6 ponds that were used in the treatment, which was carried out in a period After 15 days, the field parameters (pH, temperature, EC and DO) were monitored every 3 days during that time. Likewise, techniques and instruments were used to collect data, respectively, such as: the field record sheet, daily record, and chains of custody. The procedure was developed in stages both in the office for the systematization of information and data, and in the field to carry out the project. In conclusion, the application of macrophyte species in leachates formed in landfills is a treatment alternative, it was found that Eichhornia crassipes is more efficient than Pistia stratiotes, since it has a greater removal of pollutants to improve the quality of these waters, which that would allow giving it a different final disposition.

Keywords: Phytoremediation; Phytotechnology; Treatment; Leachates.

RESUMEN

La presente investigación titulada "eficiencia de fitorremediación de Pistia stratiotes y Eichornia crassipes en lixiviados generados en el botadero de Cuñumbuqui, San Martín 2020." tiene como objetivo general evaluar la eficiencia de la fitorremediación de las especies seleccionadas que son la Pistia stratiotes y Eichornia crassipes, esta investigación es de tipo aplicada ya que en el tratamiento, se aplicaron técnicas de fitorremediación utilizando especies macrófitas en condiciones de ex situ; con un diseño cuasi - experimental; la población correspondió a los lixiviados que se generan en el botadero de Cuñumbuqui, de la cual se obtuvo una muestra de 130L, donde se distribuyó 20L por cada uno de los 6 estanques que fueron empleados en el tratamiento, mismo que se realizó en un periodo de 15 días, los parámetros de campo (pH, temperatura, CE y OD) fueron monitoreados cada 3 días durante ese tiempo; así mismo se utilizaron técnicas e instrumentos para la recolección de datos respectivamente como: la ficha de registro de campo, registro diario y las cadenas de custodia; el procedimiento fue desarrollado por etapas tanto de gabinete para la sistematización de información y datos, como de campo para realizar la ejecución del proyecto. En conclusión, la aplicación de especies macrófitas en lixiviados formados en los botaderos si es una alternativa de tratamiento, se comprobó que la Eichhornia crassipes es más eficiente que Pistia stratiotes, ya que tiene una mayor remoción de contaminantes para mejorar la calidad de estas aguas, lo que permitiría darle una disposición final diferente.

Palabras clave: Fitorremediación; Fitotecnología; Tratamiento; Lixiviados.

INTRODUCTION

Global population growth has had a direct impact on environmental pollution due to the simultaneous generation of domestic, industrial, and mining solid waste, mainly in large cities in Latin American and Caribbean countries.[1,2,3,4] According to the United Nations Environment Programme[2], "each citizen in Latin America generates 1 kilo of waste per day and the region as a whole produces an average of 541 000 tons, representing 10 % of the world's waste," of which "45 % is not treated or disposed of properly in a landfill and other alternatives such as informal or open dumps are used",[3,5,6,7] which represent one of the most polluting and harmful forms of waste for the environment and health resulting from the improper management of solid waste. The difference in percentage is dumped into natural water sources or abandoned spaces without control or protection.[8,9,10,11]

Dumps are the main source of greenhouse gas (GHG) emissions, caused by the high organic matter content and its decomposition, which generates leachates. These are liquids formed by a process of rain percolation, forming effluents with waste residues in garbage deposits. The composition of these leachates varies according to different factors such as weather conditions or waste content, as well as their lifespan, since in young landfills, leachates have low hydrogen potential (pH) and high heavy metal content, while mature landfills have a basic pH and high ammoniacal nitrogen content (NH 3 –N) and dissolved salts, and sometimes very significant concentrations of heavy metals, affecting agricultural soils and water resources.[12,13,14,15]

In Peru, there are currently 1,585 dumps, nine sanitary landfills (in Junín, Lima, Ancash, and Cajamarca), and two safety landfills (in Lima and Ica). Landfills have a negative impact and generate risks of great impact on both the environment and health.[4] Thus, it is considered that pollution in the country is mainly due to inadequate waste management, which leads to environmental risks, due to the composition of all the waste accumulated in these spaces, which do not even have segregation processes. This is where the generation of leachates is inevitable, as they form in open spaces, where effluents are easily formed, carrying large amounts of the compounds present in the waste that directly affect the soil and surface water, as well as groundwater.[16,17,18,19]

In the San Martín Region, there is a high degree of contamination from municipal solid waste that is not disposed of properly, despite the existence of a landfill in the town of Yacucatina, district of Juan Guerra, province of San Martín.[5] Cuñumbuqui, considered a rural area, is no stranger to this reality, as its solid waste is disposed of improperly in a dump, generating leachates that contaminate potentially fertile soil for agricultural use. Similarly, nearby water effluents tend to infiltrate the soil, mainly harming natural resources and ecosystems, leading to their deterioration and the generation of diseases that can affect the population. and ecosystems, with consequences such as their deterioration and the generation of diseases that can affect the population. Therefore, it is essential to treat the leachates generated in these types of places through phytoremediation processes using macrophytic species with degrading and purifying properties for organic pollutants, in order to reduce their high toxic content and demonstrate the efficiency of this process in contaminated waters of this type. For this reason, the following problem is formulated: How efficient will the phytoremediation of Pistia stratiotes and Eichhornia crassipes be for the leachates generated in the Cuñumbuqui landfill, San Martín, 2020?[20,21,22,23]

Determining the efficiency of these two macrophytic species contributed to the results so that the municipal administration can subsequently design a treatment system for the leachate generated in the landfill. This will prevent the contamination of water sources and soil-, and therefore the existing ichthyological species that serve as food for the population, as well as the uses to which these waters are put. The aim is to contribute to solid waste management with an environmental tool, after studying and understanding the characteristics of the landfill. Among the various environmental, economic, and social benefits that will be achieved through the implementation of the leachate treatment system using phytoremediation with the species Pistia stratiotes and Eichhornia crassipes, it should be noted that this treatment system was low cost due to the minimal infrastructure required, the easy access to inputs, and the facilities provided by the municipal government.[24,25]

The development of this project seeks to contribute to the scientific field through the study of phytoremediation, as it will serve as a basis for management and be applied in situations similar to the site of implementation. It is also appropriate for municipal management to implement solid waste management plans. Techniques, methods, and research were developed that can be replicated with species native to each location where problems similar to those in the study arise. This will allow for the evaluation of the efficiency of other species, which in turn can be linked to other types of treatment to expand and ultimately ensure that leachates do not harm environmental resources and components.[26,27] The overall objective is to evaluate the efficiency of phytoremediation of Pistia stratiotes and Eichhornia crassipes in leachate generated at the Cuñumbuqui landfill in San Martín in 2020. The specific objectives are: a) To identify the characteristics of the leachate at the Cuñumbuqui landfill in San Martín in 2020. b) To design pilot ponds to be used for the treatment of leachate generated at the Cuñumbuqui landfill, San Martín 2020 c) Compare the phytoremediation efficiency of each species used in the treatment of leachate generated at the Cuñumbuqui landfill, San Martín, 2020.The following hypotheses are also proposed: H0: phytoremediation with Pistia stratiotes and Eichhornia crassipes is not efficient in leachates generated at the Cuñumbuqui landfill, San Martín 2020, and H1: phytoremediation using Pistia stratiotes and Eichhornia crassipes is effective in treating leachate generated at the Cuñumbuqui landfill in San Martín in 2020.

METHOD

Type and design of research Type of research

According to the National Council for Science, Technology, and Technological Innovation, applied research is aimed at determining, through scientific knowledge and means, whether these be technologies, methodologies, or protocols, how to meet a recognized and specific need. That is why this research was applied, since phytoremediation processes were applied to leachates using phytoremediation techniques, using macrophytic species in ex situ conditions.

Research design

Hernández, Fernández et al.[5] indicate that: "The quasi-experimental method is specifically useful for studying problems in which one does not have complete control over situations, but attempts to maintain as much control as possible. In other words, this method is used when it becomes difficult to randomly classify the objects that will participate in such studies."

Therefore, this study was conducted using a quasi-experimental design because the efficiency of leachate phytoremediation was evaluated through ex situ tests, i.e., a single experimental group was established, which was analyzed before and after treatment. The selected sample was initially evaluated. The macrophyte species were then conditioned in the pilot ponds. Finally, the post-treatment samples were analyzed to obtain results.

	Pre prueba		Post prueba
G.E.:	**P1**	**X**	**P2**

Where:
GE: Experimental group.
P1: Pre-treatment test.
P2: Post-treatment test.
X: Independent variable.

Variables and Operationalization

Variables

Independent variable: leachates from the Cuñumbuqui landfill Dependent variable: Phytoremediation efficiency.

Population, sample, and sampling Population

The population consisted of leachates generated at the Cuñumbuqui landfill with a volume of 61,500 m3.

Inclusion criteria

For the selected population, the following was considered:

Leachates resulting from the decomposition of solid waste in homogeneous areas of the Cuñumbuqui district landfill. Leachate directed to the containment pond.

Exclusion criteria

Leachate from other storage areas was not considered because it was not formed directly by waste from the landfill; that is, factors such as runoff, possible overflow from the pond, and infiltration that cause it to be contained in other areas of the landfill were taken into account.

Variables	Definición conceptual	Definición operacional	Dimensiones	Indicadores	Escala de medición
Lixiviados del botadero de Cuñumbuqui	Los lixiviados son producto de un proceso de percolación de líquidos a través de los residuos sólidos; es decir, sustancias líquidas que brotan o se infiltran hacia donde se encuentra instalado un relleno sanitario o bien un botadero" (Méndez, 2009).	Los Lixiviados se medirán de acuerdo a los métodos establecidos para los parámetros: **STS** = SMEWW-APHA-AWWA-WEF Part 2540 D, 22nd Ed. 2012, **DQO** = SMEWW-APHA-AWWA-WEF Part 5220 D, 23rd Ed. 2017, **DBO** = SMEWW-APHA-AWWA-WEF Part 5210 B, 23rd Ed.2017, **Coliformes totales** = SMEWW-APHA-AWWA-WEF Part 9221 B y C. 23rd Ed.2017, **Metales Pesados=** EPA Method 6020B Rev. 2 July (2014), (Validado Modificado, 2018).	- Agua: - Parámetros generales - Parámetros orgánicos - Parámetros biológicos	- Sólidos totales en suspensión - pH - Temperatura - CE y DO - DBO - DQO - Coliformes totales	Intervalo
Eficiencia de la fitorremediación	La Rizofiltración está basada en que ciertas plantas acuáticas, de algas, humedales, hongos y bacterias, llegan a ser buenos biosorbentes de contaminantes que están presentes en las aguas y se realiza mediante las raíces (Díez, 2008).	Se realizó Análisis de homogeneidad de los grupos y tratamientos según el diseño DBCA (Diseño de Bloques Completamente al Azar). La técnica de filtración se obtuvo mediante el método de Tukey, por último, se compararon los resultados de ambas especies con una diferencia de medias de T student.	- Eficiencia de remoción - Técnica de filtración: - *Pistia stratiotes* - *Eichhornia crassipes*	- % de remoción - % de absorción	Intervalo Razón

Figure 1. Operationalization of variables

Sample

The sample consisted of a total of 130 liters (1,3 m3) of leachate, which was distributed in six wooden tanks, each with a capacity of 20 liters, with an additional 10 liters of sample taken initially to determine the conditions of these waters prior to treatment.

Sampling

The sampling method used was non-probabilistic, as the researchers decided on the sample size, which was representative of the leachate generated at the Cuñumbuqui landfill, selecting samples according to their own conditions or criteria.

Unit of analysis

Each tank with leachate from the Cuñumbuqui landfill.

Data collection techniques and instruments

Techniques

The techniques used for the study were experimentation using pilot tests, direct observation, and description. The data obtained in the sample analyses prior to and after treatment were recorded to see the variation in our results.

Instruments

The following were used to record the data obtained in the fieldwork:

- Field record sheet: based on on-site observation, accurate information was collected that allowed us to identify specific characteristics of the object of study for later interpretation.
- Daily record sheet, to keep a written record of the data, values, and events observed during the treatment.
- The chain of custody provided by the laboratory specified the sampling, labeling, and storage procedures for the corresponding analysis.
- ODEON Ponsel multiparameter meter, necessary for measuring the following parameters: pH, temperature, EC, and DO.
- GARMIN GPS model GPSmap 62s for collecting location data on leachates.
- NIXON model 4000XS camera, used to obtain photographic evidence.

Validation

Data collection instruments such as the field record sheet and daily log were validated by specialists and research experts using an instrument validation form approved by the UCV Vice-Rector for Research. Dr. Ana Noemí Sandoval Vergara, Doctor of Education, Dr. Andi Lozano Chung, Doctor of Public Management, and Dr. Froy Torres Delgado, Doctor of Environmental Sciences.

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Procedures

The following stages were considered for the development of this research project:

Stage 1: Initial cabinet

The previously validated field record sheets and diary sheets were prepared and printed.

Macrophytic species were selected based on their potential for leachate absorption through ex situ treatment, the amount of production in the region, and the additional value of using native species.

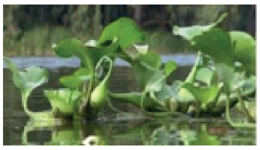
Especie1	Descripción	Figura
Eichhornia crassipes (Jacinto de agua)	- Familia: Pontederiaceae - Especie: Crassipes - Género: Eichhornia	

Figure 2. Description of Eichhornia crassipes

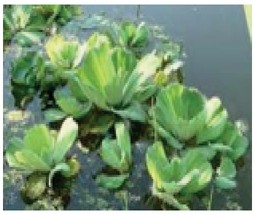
Especie2	Descripción	Figura
Pistia stratiotes (lechuga de agua)	- Familia: Araceae - Especie:Pistia stratiotes L. - Género: Pistia L.	

Figure 3. Description of Pistia stratiotes

Next, the study area was surveyed to prepare the location map.

Next, we obtained a quote from the laboratory for the analysis of the leachate samples (BOD, COD, total suspended solids, total coliforms) and coordinated the shipment and delivery of materials according to the schedule.

Stage 2: Field

To carry out the project, sampling points were identified according to the National Protocol for Monitoring Water Quality, based on the type of integrated sample, which consists of homogenizing specific samples taken at different points simultaneously to determine their conditions. This was considered since there is no national protocol for leachate sampling.

A field sheet was also used to describe the characteristics required for planning monitoring, as well as access points, geographical location data, field parameter values (pH, temperature, EC, and DO), which were evaluated with the multiparameter, site characteristics, dimensions of the leachate pond, and the location of the sampling and collection areas.

A space was set up in the district of Tarapoto that had the right conditions to avoid disruptions to the process, such as ventilation, access to sunlight, and a roof, in an area far away so as not to cause any inconvenience due to possible odors from the leachate.

The ponds were designed in 3D using AutoCAD 2017 software, then manufactured with wooden slats measuring 40 cm long x 30 cm wide x 25 cm high. Polyethylene plastic was used for the inner lining, secured with elastic strips to prevent movement, and then placed in the previously prepared space.

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Figure 4. Wooden tanks used in the treatment

The number of plants used in each treatment was determined based on the background and dimensions of the pond, since efficiency was reported to start at 10 plants. An additional 5 plants were added to test the effectiveness of the treatment, meaning that 5, 10, and 15 plants were used for both treatments.

Figure 5. Design of the ponds with the corresponding number of plants

The previously described macrophyte species were collected: Pistia stratiotes, found in the town of Santa Rosa de Cumbaza, "Ricuricocha lagoon," and Eichhornia crassipes, located in the province of La Rioja in the "Mashuyacu lagoon," 10 days prior to implementation.

Figure 6. Collection of macrophytic species

The roots of each plant were cleaned with drinking water and acclimatized in trays for a period of 10 days to remove impurities and obtain better results.

The leachate samples were collected and transported to the conditioned space.

Figure 7. Collection of leachates from the landfill / distribution of leachate in the ponds

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Samples were also taken for shipment to the INACAL-accredited ALS LS PERU S.A.C. laboratory, together with the correctly completed chain of custody (parameters to be evaluated: BOD, COD, total suspended solids, and total coliforms) in accordance with RJ 010-2016-ANA.

The methods and requirements for determining the values of the parameters evaluated in the laboratory.

Figure 8. Collection of samples for shipment to the laboratory

Field parameters were also evaluated (pH, temperature, EC, and DO) using the ODEON Ponsel multiparameter meter, and the results were recorded on the field sheet.

The macrophyte species were placed in the ponds according to the amount corresponding to each treatment.

Figure 9. Distribution of species in each of the ponds

The field parameters were monitored in each of the ponds every three days for 15 days.

On day 15, samples were taken from each pond and sent to the INACAL-accredited ALS LS PERU S.A.C. laboratory, where the following parameters were analyzed: BOD, COD, total suspended solids, and total coliforms.

Stage 3: Final assessment

Receipt of the laboratory test reports, both for the pre-treatment (in situ) considered as day 0, and the post-treatment (ex situ) of the last sampling, i.e. day 15, taken from each of the six ponds.

- The results were interpreted and compared using IBM SPSS 25 and the design (DBCA).
- The corresponding tables and graphs were prepared.
- The final report was drafted.

Data analysis method

The concentration values of the parameters obtained in the field and laboratory will be tabulated in IBM SPSS 25 software to proceed with the homogeneity analysis of the groups and treatments according to the design (DBCA). Figures showing the progress and progression of the treatment were used, and the Tukey method was applied to compare the individual means from an analysis of variance of several samples subjected to different treatments. In addition, the reference values for the LMP (pH, BOD5, COD, TSS, and total coliforms) proposed by MINAM in 2009 for the discharge of liquid effluents from solid waste treatment and leachates from sanitary and safety landfills were taken. The reference values for temperature and EC OD were taken from a similar study found in the background information and published in the scientific journal Ingeniería Hidráulica y Ambiental.

Ethical aspects

The project was carried out in strict accordance with the thesis development process and the guidelines of the Cesar Vallejo University, which establish the format for research projects. In accordance with the ethics of each researcher, the information obtained from research papers, scientific articles, and institutional websites related to different authors helped us to improve the theory of this research without modifying or changing the references obtained, thus respecting copyright. For laboratory work, it was necessary to follow biosafety standards for the prevention of hazards during work. The laboratory results were not altered in order to ensure the formal nature of the research.

RESULTS

Description of the Cuñumbuqui municipal landfill

The figure 10 shows the characteristics of the landfill.

Características			
Tipo de botadero	Residuos sólidos ingresados	Tipo de municipio	Edad
Cielo abierto	1,8 ton (semanal)	Rural	Mas de 20 años

Figure 10. Characteristics of the landfill

Interpretation

The landfill located in the rural area of the Cuñumbuqui district has been in operation for more than 20 years and receives an average of 1,8 tons per week. As a landfill, it has characteristics such as an open sky, almost open access for people, and is located 10 minutes from the city.

Identification of the characteristics of the leachates

Parámetro	Unidad	LIXI 1	Valor referencial
pH	-	6.60	6,5-8,5
CE	mg/L	6,82 μs/cm	3,5
OD	mg/L	0.0 %	2
T (°C)	mg/L	21.57 °C	50
DBO_5	mg/L	136	20
DQO	mg/L	351	120
SST	mg/L	77	30
Coliformes totales	NMP/100mL	2400	1000

Figure 11. Characteristics of leachate

Interpretation

Figure 11 shows the characteristics of the leachates, which are the parameters with their respective units. It also contains the values obtained in the previous analysis, which was determined as LIXI 1, comparing them with reference values, where the pH is slightly acidic. With respect to OD, the results were zero, indicating anoxia in the leachates. The BOD5 and COD concentrations were high, indicating a high organic matter content. A high total coliform content was also found.

Pond design

Especie	Dimensiones (cm)	Cantidad (V)	Tratamiento
Eichhornia crassipes	40cm x 30cm x 25cm	25cmx 20 L	1
			2
			3
Pistia stratiotes			1
			2
			3

Figure 12. Pond design

Interpretation

The ponds for each treatment were designed based on the dimensions of 40 cm x 30 cm x 25 cm, which was the volume of water used.

Analysis of homogeneity of groups and treatments according to the CRLD (Completely Randomized Block Design).

To accept or reject the null hypothesis, we proposed the following hypothesis:

Ho: If the significance value (sig.) is greater than or equal to 0,05, we accept that there is no significant difference between the groups or treatments in the research; the groups and treatments are homogeneous.

Ha: If the significance value (sig.) is less than 0,05, we accept that there is a significant difference between the groups or treatments in the research; the groups and treatments are heterogeneous.

Homogeneity test for pH

DBCA	GRUPOS		
	Grupo Control	*Eichhornia crassipes*	*Pistia stratiotes*
Tratamiento 1	6,32	6,32	6,36
Tratamiento 2	6,32	6,34	6,34
Tratamiento 3	6,32	6,41	6,32

Figure 13. DBCA matrix for pH

Interpretation

Shows the pH values obtained at the start of the experiment, which should provide homogeneity in the results, which is the principle of scientific research; that is, the media are controlled by the researchers.

Origen	Suma de cuadrados tipo III	gl	Media cuadrática	F	Sig.
Modelo corregido	,003[a]	4	,001	,547	**,713**
Intersección	361,634	1	361,634	307047,406	,000
Grupos	,002	2	,001	,858	**,490**
Tratamientos	,001	2	,000	,236	**,800**
Error	,005	4	,001		
Total	361,641	9			
Total corregida	,007	8			

Figure 14. Pre-test results for pH– DBCA

Interpretation

As the significance value of the model (0,713), the groups (0,490), and the treatments (0.0.800) are greater than the error (0,05), we accept the null hypothesis that there is no significant difference between the groups or treatments in the research; the groups and treatments are homogeneous for pH.

Homogeneity test for BOD5

DBCA	GRUPOS		
	Grupo Control	*Eichhornia crassipes*	*Pistia stratiotes*
Tratamiento 1	136	136	136
Tratamiento 2	136	136	136
Tratamiento 3	136	136	136

Figure 15. DBCA - BOD5 matrix

Interpretation

The BOD5 values obtained at the start of the experiment, which should provide homogeneity in the results, which is the principle of scientific research and homogeneity; that is, the media are controlled by the researchers. Because the results are constant, we deduce that the groups and treatments are hom.

Homogeneity test for SST

DBCA	GRUPOS		
	Grupo Control	*Eichhornia crassipes*	*Pistia stratiotes*
Tratamiento 1	77	77	77
Tratamiento 2	77	77	77
Tratamiento 3	77	77	77

Figure 16. DBCA matrix for SST

Interpretation

The SST values obtained at the start of the experiment, which should provide homogeneity in the results, which is the principle of scientific research; that is, the means are controlled by the researchers. Because the results are constant, we deduce that the groups and treatments are homogeneous.

Post-test of the groups and treatments according to the DBCA design (Completely Randomized Block Design).

To accept or reject the null hypothesis, we propose the following hypothesis:

Ho: if the significance value (sig.) is greater than or equal to 0,05, we accept that there is no significant difference between the groups or treatments in the research; the groups and treatments are homogeneous.

Ha: if the significance value (sig.) is less than 0,05, we accept that there is a significant difference between the groups or treatments in the research; the groups and treatments are heterogeneous.

Post-test for pH

DBCA	GRUPOS		
	Grupo Control	*Eichhornia crassipes*	*Pistia stratiotes*
Tratamiento 1	7,24	7,74	7,93
Tratamiento 2	7,24	7,60	7,88
Tratamiento 3	7,24	7,46	7,60

Figure 17. DBCA matrix for pH

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Interpretation

The pH values obtained at the end of the experiment, which should provide us with heterogeneity in the results, which is the objective of this scientific research; that is, the media are controlled by the researchers to test possible differences between groups and treatments.

Origen	Suma de cuadrados tipo III	gl	Media cuadrática	F	Sig.
Modelo corregido	,553[a]	4	,138	14,749	**,012**
Intersección	512,721	1	512,721	54673,992	,000
Grupos	,488	2	,244	26,034	**,005**
Tratamientos	,065	2	,032	3,463	,134
Error	,038	4	,009		
Total	513,311	9			
Total corregida	,591	8			

Figure 18. Post-test results for pH– DBCA

Interpretation

As the significance value of the model (0,012) is less than the error (0,05), we reject the null hypothesis and accept the alternative hypothesis that there is a significant difference between the groups or treatments in the research. the groups and treatments are heterogeneous. We can observe that the significance value for the groups (0,005) indicates a significant difference, while the significance value for the treatments (0,134) does not.

(I)Grupos		Sig.	(I)Tratamientos		Sig.
Grupo Control	*Eichhornia crassipes*	**,023**	al 5%	al 10%	,722
	Pistia stratiotes	**,005**		al 15%	,127
Eichhornia crassipes	Grupo Control	**,023**	al 10%	al 5%	,722
	Pistia stratiotes	,127		al 15%	,289
Pistia stratiotes	Grupo Control	**,005**	al 15%	al 5%	,127
	Eichhornia crassipes	,127		al 10%	,289

Figure 19. Multiple post-test comparisons of pH – Tukey method

Interpretation

There is a significant difference in pH concentration in the groups, control group, Pistia stratiotes group, and Eichhornia crassipes sig. (0,005, 0,023< 0,05); there is no significant difference in the treatments.

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Grupos		Media Tratamientos	Media Grupo
Grupo Control	al 5%	7,240	7,240
	al 10%	7,240	
	al 15%	7,240	
Eichhornia crassipes	al 5%	7,740	7,600
	al 10%	7,600	
	al 15%	7,460	
Pistia stratiotes	al 5%	**7,930**	**7,930**
	al 10%	7,880	
	al 15%	7,600	

Figure 20. Summary of pH averages

Interpretation

It was determined that there is a significant difference between groups, with the Pistia stratiotes group having the most basic pH; there was no significant difference in the treatments; however, the highest average pH is observed in the 5 % treatment in descriptive form.

Post-test for BOD5

DBCA	GROUPS		
	Control group	*Eichhornia crassipes*	*Pistia stratiotes*
Treatment 1	86	2	5
Treatment 2	86	5	3
Treatment 3	86	4	6

Figure 21. DBCA matrix for BOD5

Interpretation

The BOD5 values obtained at the end of the experiment, which should provide heterogeneity in the results, which is the objective of this scientific research; that is, the media are controlled by the researchers to test possible differences between groups and treatments.

Origen	Suma de cuadrados tipo III	gl	Media cuadrática	F	Sig.
Modelo corregido	13396,444[a]	4	3349,111	1722,400	**,000**
Intersección	8898,778	1	8898,778	4576,514	,000
Grupos	13394,889	2	6697,444	3444,400	**,000**
Tratamientos	1,556	2	,778	,400	,694
Error	7,778	4	1,944		
Total	22303,000	9			
Total corregida	13404,222	8			

Figure 22. Post-test results for BOD5 - DBCA

Interpretation

As the significance value of the model (0,000) is less than the error (0,05), we reject the null hypothesis and accept the alternative hypothesis that there is a significant difference between the groups or treatments in the research. the groups and treatments are heterogeneous. We can observe that the significance value for the groups (0,000) indicates a significant difference, while the significance value for the treatments (0,694) does not.

(I)Groups		Sig.	(I)Treatments		Sig.
Control group	*Eichhornia crassipes*	**,000**	at 5%	at 10%	,954
	Pistia stratiotes	**,000**		to 15%	,680
Eichhornia crassipes	Control Group	**,000**	to 10%	at 5%	.954
	Pistia stratiotes	,680		15%	,835
Pistia stratiotes	Control group	**,000**	at 15%	at 5%	,680
	Eichhornia crassipes	,680		10%	,835

Figure 23. Multiple post-test comparisons of BOD5 – Tukey method

Interpretation

There is a significant difference in the concentration of BOD5 in the control groups, the Pistia stratiotes group, and the Eichhornia crassipes group, sig. (0,000< 0,05); there is no significant difference in the treatments.

Grupos		Media Tratamientos	Media Grupo
Grupo Control	al 5%	86	86,00
	al 10%	86	
	al 15%	86	
Eichhornia crassipes	al 5%	2	**3,67**
	al 10%	**5**	
	al 15%	4	
Pistia stratiotes	al 5%	5	4,67
	al 10%	3	
	al 15%	6	

Figure 24. Summary of BOD5 averages

Interpretation

It was determined that there is a significant difference between groups, with the lowest concentrations of BOD5 in the Pistia stratiotes and Eichhornia crassipes groups; there was no significant difference in the treatments, however, we can highlight the Eichhornia crassipes group with the 10 % treatment.

Post-test for SST

DBCA	GRUPOS		
	Grupo Control	*Eichhornia crassipes*	*Pistia stratiotes*
Tratamiento 1	45	18	4
Tratamiento 2	45	29	4
Tratamiento 3	45	32	16

Figure 25. DBCA matrix for SST

Interpretation

The SST values obtained at the end of the experiment, which should provide heterogeneity in the results, which is the objective of this scientific research; that is, the means are controlled by the researchers to test possible differences between groups and treatments.

Source	Sum of squares type III	gl	Quadratic mean	F	Sig.
Corrected model	2167.111[a]	4	541,778	23,785	**.005**
Intersection	6,293.778	1	6,293.778	276,312	,000
Groups	2053,556	2	1,026,778	45,078	**,002**
Treatments	113,556	2	56,778	2,493	,198
Error	91,111	4	22,778		
Total	8,552,000	9			
Total adjusted	2,258.22	8			

Figure 26. Post-test results for SST – DBCA

Interpretation

As the significance value of the model (0,005) is less than the error (0,05), we reject the null hypothesis and accept the alternative hypothesis that there is a significant difference between the groups or treatments in the research. the groups and treatments are heterogeneous. We can observe that the significance value for the groups (0,002) indicates a significant difference, while the significance value for the treatments (0,198) does not.

(I)Groups		**Sig.**	**(I)Treatments**		**Sig.**
Control group	*Eichhornia crassipes*	**,019**	at 5%	at 10%	.647
	Pistia stratiotes	**.002**		to 15%	,180
Eichhornia crassipes	Control Group	**,019**	to 10%	at 5%	.647
	Pistia stratiotes	**.020**		at 15%	.474
Pistia stratiotes	Control group	**,002**	at 15%	at 5%	.18
	Eichhornia crassipes	**,020**		to 10%	,474

Figure 27. Multiple post-test comparisons of SST – Tukey method

Interpretation

There is a significant difference in the concentration of SST in the control groups, Pistia stratiotes group, and Eichhornia crassipes group, sig. (0,002, 0,019, 0,020< 0,05); there is no significant difference in the treatments.

Grupos		**Media Tratamientos**	**Media Grupos**
Grupo Control	al 5%	45	45
	al 10%	45	
	al 15%	45	
Eichhornia crassipes	al 5%	18	26,33
	al 10%	29	
	al 15%	32	
Pistia stratiotes	al 5%	**4**	**8**
	al 10%	4	
	al 15%	16	

Figure 28. Summary of SST averages

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Interpretation

It was determined that there is a significant difference between groups, with the lowest SST concentrations in the Pistia stratiotes group; there was no significant difference in the treatments, however, we can highlight the 5 % treatment.

Comparative analysis of parameters

Statistics	***pH***	***BOD5***	***TSS***
Pre-test mean	6.339	136,000	77,000
Post-test average	7,548	31,444	26,444
T-statistic	-13.264	7,663	9,027
P(T<=t) one tail	**0**	**0**	**0**
Critical value of t (one tail)	-1.86	1.860	1

Figure 29. Student's t-test for parameter means

Interpretation

When comparing the pre- and post-test parameters under study, we can see that there is a significant difference in the results, since the one-tailed Student's t-test probability (0,000) is less than the error (0,05). When analyzing the difference in means for the pH parameter, we observe that the post-test is higher than the pre-test, and for the BOD5 and SST parameters, the opposite is true, with lower averages in the post-test compared to the pre-test, which is what is expected.

DISCUSSION

The disposal of solid waste in landfills generates leachates with high polluting capacity, causing serious environmental impacts on both surface and groundwater sources, as well as on the soil. Therefore, this project is considered important for contributing to the conservation of natural resources.[28,29]

The characteristics of the leachates were identified through factors such as composition, age of the landfill, and amount of waste entered. In addition, a physical-chemical, organic, and biological analysis was performed, and the results indicated that there is indeed a high concentration of these compounds (TSS, BOD5, COD, and total coliforms) were found, as well as a slightly acidic pH. OD values were zero, and temperatures were normal, typical of the climate in the area, as indicated by Pellón et al.[6] whose objective was to characterize leachates and estimate their generation in a landfill in Havana (city), similarly demonstrated that leachates are characterized by high concentrations of mainly organic compounds (BOD5 and COD), TSS, and pathogenic microorganisms (coliforms). The OD values were almost zero and the temperature was appropriate for the climate of the area, so it can be deduced that there is not much variation in the leachates formed in landfills in different territories.[30,31]

The ponds were designed in advance in a 3D format in order to have a model with the dimensions of each side to facilitate construction. The materials used, such as wood and tape, were recycled, reducing costs. At the end of the project, the ponds were donated to a researcher who will carry out a similar project. Fasani et al.[7] mention that their experiment was carried out in pots to contain leachate leaks, meaning that the design for the treatments was different in each study.

During the 15 days of treatment, five field parameter monitoring sessions were carried out, and the evolution of the plants and leachates was observed. From the third day of monitoring, the plants of the species Pistia showed slight degradation of the leaves. On the fifth monitoring, these changes were more noticeable, as the leaves were almost completely degraded and the leachates were lighter in color. Eichhornia crassipes showed no changes in its plants but did show changes in the leachates, as their dark color lightened. In contrast, in monitoring 5, a dark color was present in the roots and stems, and the lightening of the leachates was more noticeable in this treatment.[32,33]

After obtaining the monitoring and laboratory results, the components evaluated were compared between the two species. There is a significant difference between the groups, with the Pistia stratiotes group having the most basic pH. even so, the highest average pH (7,930) was observed in the treatment with 5 plants. There was no significant difference between the treatments; however, it should be noted that the Eichhornia crassipes group had a BOD5 of 86, which decreased to 5 in the treatment with 10 plants. The difference in the mean pH parameter, where the post-test is higher than the pre-test, and in the BOD5 and SST parameters, the opposite is true, with lower means in the post-test compared to the pre-test, which is what was expected in

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the final results. According to this, it can be said that Pistia stratiotes is more efficient in the phytoremediation of leachates. Similarly, Sari et al.[8], in their research: "The Effectiveness of Filter Media and Echinodorus palaefolius on Phytoremediation of Leachate," demonstrated that there was a significant effect on leachate quality when filter media and the species Echinodorus palaefolius were used for treatment, concluding that Echinodorus palaefolius is better for phytoremediation of leachates.[34,35]

CONCLUSIONS

The efficiency of the species Pistia stratiotes and Eichhornia crassipes was evaluated, with the result that Pistia stratiotes was more efficient than Eichhornia crassipes, as it has a higher removal of contaminants to improve the quality of these waters, given that the application of these macrophytic species in leachates formed in landfills is an alternative treatment, which would allow for a different final disposal.

The characteristics of the leachates were identified as pH 6,6, EC 1506, OD 41,23, BOD5 136 mg/L, COD 351 mg/L, TSS 77 mg/L, total coliforms 2400, and temperature 21,57°. These values indicated that the water exceeded all MPCs, except for temperature and pH, which were within the MPCs after analysis of the values evaluated in the field. These leachate waters correspond to the Cuñumbuqui landfill.

The design was initially structured in a virtual 3D model format, considering the necessary volume of 20 liters for the species, the height for their aeration, and the number of species. After that, it was physically constructed using recycled wood and rubber with dimensions of 40 cm x 30 cm x 25 cm. The structure was ultimately functional for the development of the research.

From the comparison between the species Pistia stratiotes and Eichhornia crassipes, it was concluded that Pistia stratiotes, in treatment 2 with 10 species, was the most efficient.

RECOMMENDATIONS

The municipality of the district of Cuñumbuqui should improve its solid waste management by implementing recycling, segregation, and even reuse programs, with innovative proposals aimed at the population.

Municipalities located in rural areas should implement this type of treatment for the leachate generated in their respective landfills, with the aim of stopping or reducing the production of this polluting liquid, emphasizing that it is a low-cost system with no drawbacks and very good results. The species used are found in the area, so acquiring them is not complicated.

The professionals responsible for the environmental area of the district municipality of Cuñumbuqui should treat leachate to prevent direct contamination of natural resources and provide an alternative for reusing leachate.

Inform the population about the current situation regarding solid waste control and management, as according to the study, the district lacks action on this issue. From there, raise awareness by promoting environmental education through workshops on the importance and benefits of good solid waste management.

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CONFLICT OF INTEREST

Authors declare that there is no conflict of interest.

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