(04-017) - ALTERNATIVES FOR SEWAGE SLUDGE TREATMENT: WETLANDS FOR SLUDGE DEWATERING - PILOT SCALE EXPERIMENTATION.

Leigue Fernández, María Alejandra [1]; Angulo Reyes, María Rosalva [1]; Zenteno Sardina, Ivis Camila [1]

[1] UNIVERSIDAD CATÓLICA BOLIVIANA SAN PABLO - CIICE

In Bolivia, the increase in wastewater treatment plants has generated a greater production of sludge, which requires proper management due to its impact on operating costs. Agricultural reuse is considered a viable destination for sludge, and constructed wetlands are recognized as a sustainable and economical technology. In this experiment, two different types of sludge (LA and LB) were analyzed in duplicate, using cattail (Typha Domingensis Peerson) as plant material with sludge from the San Luis facultative lagoon (LA) and from the Catedral wastewater treatment plant, activated sludge (LB) in the city of Tarija. Moisture, volatile solids (VS), total Kjeldahl nitrogen (TKN), total phosphorus (Pt) and root regeneration were evaluated. Moisture reduction exceeded 80. Although LB presented higher plant density at the end of the experiment, it did not achieve efficient removal because it contained huge amounts of nitrogen compared to LA. The removal of phosphorus contained in the dewatered sludge at the end of the experiment was 96% and 94% for LA-1_out and LA-2_out and 98% and 99% for LB-1_out and LB-2_out. While the removal of volatile solids was partial.

Keywords: sewage sludge; constructed wetlands; dewatering

ALTERNATIVAS PARA TRATAMIENTO DE LODOS RESIDUALES: HUMEDALES PARA SU DESHIDRATACIÓN - EXPERIMENTACIÓN A ESCALA PILOTO.

En Bolivia el aumento de las plantas de tratamiento de aguas residuales ha generado una mayor producción de lodos, lo que requiere una gestión adecuada debido a su impacto en los costos operativos. La reutilización agrícola se considera un destino viable para los lodos, y los Humedales Artificiales son reconocidos como una tecnología sostenible y económica. En esta experimentación se analizaron por duplicado dos tipos diferentes de lodos (LA y LB), utilizando totora (Typha Domingensis Peerson) como material vegetal con lodos provenientes de la Laguna facultativa de San Luis (LA) y de la depuradora Catedral, lodos activados (LB) en la ciudad de Tarija. Se evaluaron la humedad, sólidos volátiles (VS), nitrógeno total Kjeldahl (TKN), fósforo total (Pt) y regeneración radicular. La reducción de la humedad superó el 80. A pesar de que LB presentó mayor densidad de plantas al final de la experimentación, no logró una remoción eficiente debido a que contenía enormes cantidades de nitrógeno comparado con LA. La eliminación del fósforo contenido en los lodos deshidratados al final de la experimentación fue de 96% y 94 % para LA-1_out y LA-2_out y 98% y 99% para LB-1_out y LB-2_out. Mientras que la remoción de solidos volátiles fue parcial.

Palabras clave: lodos residuales; humedales artificiales; deshidratación

Correspondencia: aleigue@ucb.edu.bo

Agradecimientos: VLIR-UOS: Vlaamse Interuniversitaire Raad-Universitaire Ontwikkelingssamenwerking and by the DGD: Directorate General for Development Cooperation and Humanitarian Aid of the Kingdom of Belgium.

1. Introduction

Sludge management has become a crucial issue in urban and industrial wastewater treatment mainly for two reasons: 1) large quantities of sludge are generated as waste or by-products of wastewater treatment processes; 2) solid waste handling and disposal are among the most complex problems of wastewater treatment facilities (Uggetti, Ferrer, Llorens, & García, 2010)

Wastewater treatment is a process where chemical, biological and physical transformations occur, the main objective is to remove the pollutants present in the water so that they can meet the quality requirements in relation to the class of the receiving body where the treated water will be discharged such as lakes, rivers, reservoirs, etc. However, wastewater treatment generates large quantities of sludge at various stages of the process; treatment, reuse and/or disposal. The characteristics of sludge are conditioned by the origin of the wastewater, the treatment process, and the time of year.

Sewage sludge management is a critical environmental issue and one of the most costly processes in municipal wastewater treatment, (Stefanakis, Komilis, & Tsihrintzis, 2011). According to (Cabero Ugalde, 2017): sludge represents only 1% to 2% of the volume of treated wastewater, its management is very complex and has a cost that generally ranges from 20% to 60% of the total operating cost of a wastewater treatment plant (WWTP). In addition to its economic importance, the final destination of sludge is a complex operation, as it is often performed outside the treatment plant boundaries.

Therefore, there is a need to look for new technological alternatives for sewage sludge treatment that are low cost, with simple operation and maintenance requirements and with a lower environmental impact. Meaning that are in accordance with our reality and, above all, for peri urban and rural sectors, where sludge can be beneficially used. The treatment and final disposal of sludge generated in WWTPs is a very important process and due to the lack of knowledge of its possible use and the cost it represents, sludge is disposed of in sanitary landfills without prior treatment, losing its potential as a soil improver. This sludge generally contains large amounts of organic matter, nutrients, heavy metals, microorganisms and in most cases the sludge collected is disposed of in sanitary landfills without prior treatment that would allow appropriate protective measures to be taken to prevent contamination of groundwater, soil or the attraction of vectors, generating environmental and public health contamination problems.

Over the years, considering population growth, large volumes of sewage sludge are generated on a daily basis. Due to this considerable increase, treatment and stabilization becomes a problem for WWTPs, as current technological solutions face limitations, as sewage sludge is characterized by a high-water content (80-90%), even if treated mechanically.

The research problem is posed; To what extent is it possible that sewage sludge from WWTPs in the city of Tarija can be treated by nature-based treatment processes?

At the regulatory level, there is a legal vacuum in Bolivia regarding the management and handling of sewage sludge, which makes it difficult to control and monitor this waste (which is not used) and to seek possible solutions to prevent it from continuing to be disposed of in places where it generates water, soil and environmental contamination and consequently, the wastewater treatment plants (WWTP) at the local level do not have a sludge treatment system. In the particular case of the San Luis lagoon system in the city of Tarija, there is no sludge treatment system; moreover, the maintenance given to these plants has been very precarious and infrequent, and they have already completed their life cycle.

According to the new Technical Guide for the Selection and Design of Wastewater Treatment Lines (Centro de las Nuevas Tecnologías del Agua, 2021), the revision of the sludge treatment chapter only addresses the different treatment lines that can be used and recommendations for their sizing according to the type of sludge; however, it does not include permissible limits for their correct final disposal.

Constructed or artificial wetlands are a technology that reproduces and takes advantage of the physical, chemical and biological mechanisms of water purification that occur in natural wetlands, for the elimination of pollutants present in wastewater. The system consists of the development of a rooted macrophyte culture on a waterproofed gravel bed (Delgadillo, Camacho, Pérez, & Andrade, 2010). It represents a natural alternative, easy to implement, with low operation and maintenance costs due to low energy consumption, and adaptable to different levels of treatment; they also have the capacity to efficiently eliminate suspended materials, nutrients and different pollutants found in wastewater.

The most used macrophytes in wetlands can be differentiated into emergent, floating, free-floating and submerged. There is a record of more than 150 species of macrophytes used in studies of artificial wetlands; however, only a limited number of plants have been used in wetlands for wastewater treatment (Wu, y otros, 2015).

Some research has been carried out on the artificial wetlands technique for the dewatering and stabilization of sewage sludge; the following are the results of the studies and experiences on the subject.

In the study by (Giraldi, y otros, 2009) where a hydraulic and biochemical analysis of artificial wetlands for large-scale sludge treatment in Italy was performed, it was determined that this technique is an efficient and economical solution for sludge management in small wastewater treatment plants. The experimentation was carried out over a total of four years, evaluating the macrophytes with respect to sludge dewatering, mineralization and humification. The results indicate a decrease in sludge volume of approximately 93% per year.

According to the research conducted by (Troesch, Lienard, Molle, Merlin, & Esser, 2009), a full scale and pilot study for activated sludge treatment applying the reed bed technique. Eight pilots of 2m² each and a full-scale plant, with 8 beds and in operation for 4 years, were carried out, during the whole study the hydraulic behavior (infiltration rate, outflow), relative O2 and CO2 concentrations in the filter media, redox potential, pollutant removal and dry matter content were evaluated.

Research on sludge dewatering and stabilization in reed beds by (Uggetti, y otros, 2009) demonstrated good efficiency in the context of small remote wastewater treatment plants, research conducted in Catalonia, Spain, where three large-scale systems were evaluated. Samples of influent sludge and sludge accumulated in the beds, pH, electrical conductivity, total solids (TS), volatile solids (VS), chemical oxygen demand, biochemical oxygen demand, nutrients (total Kjeldahl nitrogen (TKN) and total phosphorus (TP), heavy metals and fecal bacteria indicators (*Escherichia coli* and *Salmonella spp*) were analyzed. Progressive organic matter removal and sludge stabilization was observed in the beds (VS concentration decreased from 52-67% ST in the influent to 31-49% ST in the beds). The nutrient concentration of the sludge accumulated in the beds was quite low (TKN 2-7% ST and TP 0.04-0.7% ST), and heavy metals remained below the limit of law. E. coli concentrations were below 460 MPN/g in the sludge accumulated in the beds.

2. Goal

To evaluate the feasibility of implementing vertical flow constructed wetlands for sewage sludge through a pilot scale model, using sludge from the Catedral WWTP: activated sludge technology and the facultative lagoon of the San Luis WWTP in Tarija.

- Analyze and compare the experimental data with the artificial wetland treatment technique for sewage sludge.
- Analyze the effect of sludge treatment during the experimental period, comparing the results of the initial characterization with those obtained at the end in terms of moisture content and nutrient removal.
- Evaluate the behavior of the plant species through regeneration and root development achieved at the end of the research.

3. Materials and methods

3.1 Preparation of constructed wetlands at pilot scale

The research consisted in the application of the technique of constructed wetlands of vertical flow at pilot scale, cultivated with cattail (*Typha Dominguensis Persoon*); constituted by four experimental units, LA-1 and LA-2 fed with residual sludge collected from the San Luis Lagoon, LB-1 and LB-2 fed with activated sludge from the Catedral WWTP, each one composed of 2 plants/m2. The quality of sewage sludge and the treatment technologies used in WWTPs can influence the final characteristics of sewage sludge (Kacprzak, y otros, 2017).

The experiment was carried out in a total of 65 days, where sludge samples were taken at the beginning and at the end to analyze the dehydration and stabilization of the sludge through the evaluated parameters: Moisture, Total Kjeldahl Nitrogen (TKN), Total Phosphorus, Volatile Solids.

In addition, the regeneration of the plants was counted during the time the research was carried out and the roots were measured at the end of the process; these data were compared with the control, which has the same structure as the wetlands, but smaller and fed with clean water throughout the study period.

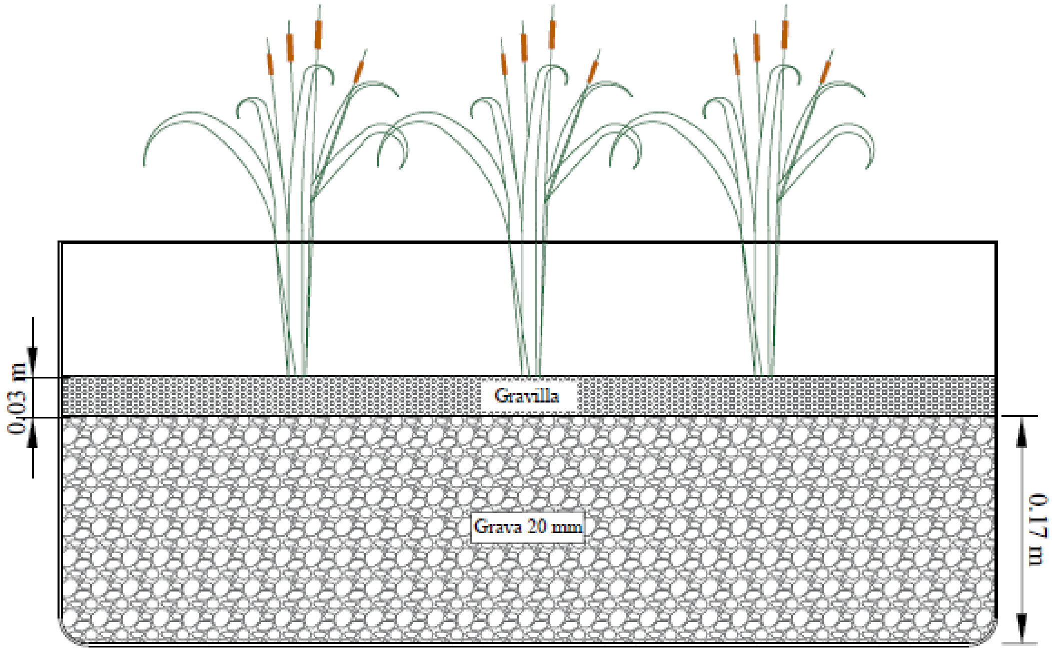
Among the systems studied and according to the characteristics of the sewage sludge treatment, the system that best addresses this type of conditions is the Vertical Flow Constructed Wetland, because the sludge was poured vertically and the liquid contained in the sludge is infiltrated thanks to the granular medium it presents, therefore, there is a significant decrease in the liquid present.

The containers used in the research are PVC trays, in which a drainage system was installed, which has a 25.4 mm diameter PVC, with a catchment system across the width of the container that will allow the water contained in the sludge to drain out.

The gravel layers used for drainage were 20 mm for the lower layer and 6 mm gravel for the upper layer, to allow water drainage in the sludge and the retention of solids on the upper layer. Each wetland consisted of 6 plants initially, with a separation of 0.2 m from plant to plant and an average height of 1 m for each plant. Obtaining an approximate volume of 0.24 m^3 and 0.04 m^3 respectively for the preparation of the four wetlands and samples.

The 20 mm gravel was poured first at a height of approximately 0,17 m followed by the 6 mm gravel at a height of 0.03 m, leaving a free edge of 0.2 m for the sludge feed that was poured throughout the experiment (Figure 1).

Figure 1: Structure of constructed wetlands.



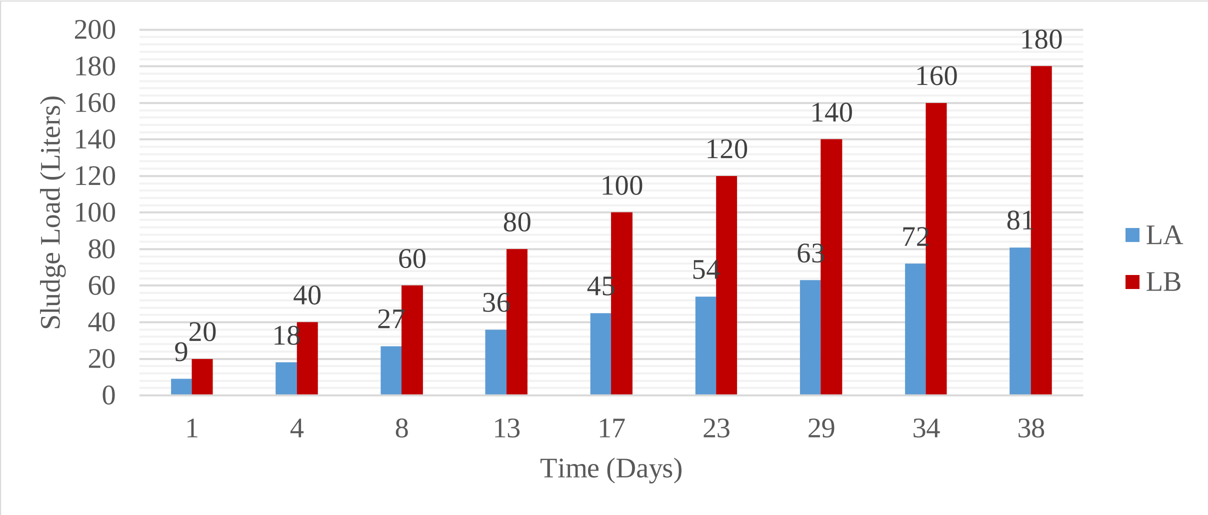
Source: Own elaboration, 2022

Then the species was planted, where six plants were used per wetland, distributed at 0,2 m between each plant.

The plant species used in the system was cattail (*Typha dominguensis Persoon*) which offers good adaptability given its high evapotranspiration capacity as well as its availability in the environment (Erazo Campos, 2004). These plants have a great resistance to various conditions, presence of salts, pollutants, microorganisms, etc. (Silva Tipantasig, 2019). Cattails have also been widely used in wetland treatment, particularly due to their high initial growth rate (Uggetti, Ferrer, Llorens, & García, 2010)

Feeding of the wetlands with both sludges was carried out at a frequency of 1 day of feeding and 4 days of rest. For LA sludge the loading frequency was 9 liters, while for LB sludge it was 20 liters. This difference in volumes is due to the physical characteristics of the sludge collected. With a total of 9 loads in 38 days, obtaining a sludge loading rate for LA of 81 liters and for LB of 180 liters at the end of the feeding (Figure 2).

Figure 2: Sludge loading frequency.



Source: Own elaboration, 2022

3.2 Initial characterization

The initial characterization of both sludges was carried out by analyzing each of the proposed parameters at the S.A. LABS of the Universidad Católica Boliviana with different methods; for example: The 105°C drying technique was used to determine the moisture content and so on. The results are shown in table 1.

Table 1: Initial laboratory sludge characterization

Parameter	Unit of measure	Analysis Method	LA	LB
Moisture	%	Drying oven	81.6	98.6
Volatile Solids	% on dry matter	Calcination	27.6	71.4
Pathogens	N° UFC of *E. coli*	Membrane filtration	1.0E+08	9.0E+07
pH	pH scale	pH-meter	6.1	5.9
Conductivity	µs/cm	Conductivity meter	1,052.0	958
Nitrites	mg/l	Spectrophotometry	17.9	118.5
Nitrates	mg/l	Spectrophotometry	17.9	81,821.0
Ammonia	mg/l	Spectrophotometry	806.8	1,319.1
Total Kjeldahl Nitrogen (TKN)	mg/l	Spectrophotometry	2,309.0	6,133.0
Total Phosphorus (TP)	mg/l	Spectrophotometry	61,336.0	62,738.0
Biochemical Oxygen Demand	mg/l	Respirometric method	2,190.0	4,830.0
Chemical Oxygen Demand	mg/l	Digestion	1.3E+06	1.7E+06

Source: Own elaboration, 2022

3.3 Final sample collection

The final samples were taken to analyze all the parameters in the laboratory. For this purpose, samples of the homogenized dehydrated sludge were collected, the roots were measured, and the total volume was calculated.

The same laboratory analyses of the initial characterization were carried out, and the results can be seen in Table 2.

Table 2: Experimental treatment results.

Parameter	Unit	INITIAL		FINAL					
		LA	LB	LA-1	LA-2	LB-1	LB-2	LA-11	LA-21
Moisture	%	81.6	98.6	4,50	3,60	10,80	11,00	19,10	19,10
Volatile Solids	% on dry matter	27.6	71,40	19,80	18,20	67,60	69,00	*****	*****
Total Coliforms	N° CFU	1.4E+09	1.4E+08	1.7E+09	7.1E+08	8.6E+08	9.4E+08	7.0E+08	8.6E+08
Fecal Coliforms	N° CFU	1.0E+08	9.0E+07	7.0E+08	2.8E+08	1.5E+08	1.1E+08	6.0E+07	1.5E+08
pH	Rango de pH	6.1	5.9	4.5	5.0	6.5	6.3	5.6	5.4
Conductivity	µs/cm	1,052.0	958.0	207.40	231.0	279.0	301.0	45.7	48.1
Nitrites	mg/l	17,946.0	118.5	35.2	29.9	58.1	47.8	56.2	42.2
Nitrates	mg/l	16,224.0	81,821.0	6,699.3	3,825.1	5,112.1	7,889.2	8,577.0	6,139.9
Ammonia	mg/l	806.8	1,319.1	1,907.1	1,266.5	1,312.4	1,096.2	853.3	1,151.7
TKN	mg/l	2,309.0	6,133.0	1,203.0	1,322.0	17,820.0	19,273.0	7,446.0	6,274.0
TP	mg/l	61,336.0	62,738.0	11,498.0	14,430.0	5,406.2	4,191.9	1,109.4	7,737.6
BOD5	mg/l	2,190.0	4,830.0	1,260.0	1,220.0	8,530.0	8,990.0	690.0	710.0
COD	mg/l	1.3E+06	1.6E+06	3.6E+05	2.9E+05	3.3E+05	2.4E+05	1.9E+05	2.2E+05

Source: Own elaboration, 2022

From the first analysis in Table 2, it was convenient to analyze the most representative parameters, i.e., the removal efficiencies of the parameters that can show the characteristics of the treated sludge, according to the objective set out in the initial stage (red highlighted parameters).

- Sludge dewatering: Moisture content.
- Nutrients: Nitrogen (TKN) and Total Phosphorus (TP).
- Volatid solids, only to verify the stability of the sludge in the experimental period.

3.4. Regeneration of macrophytes

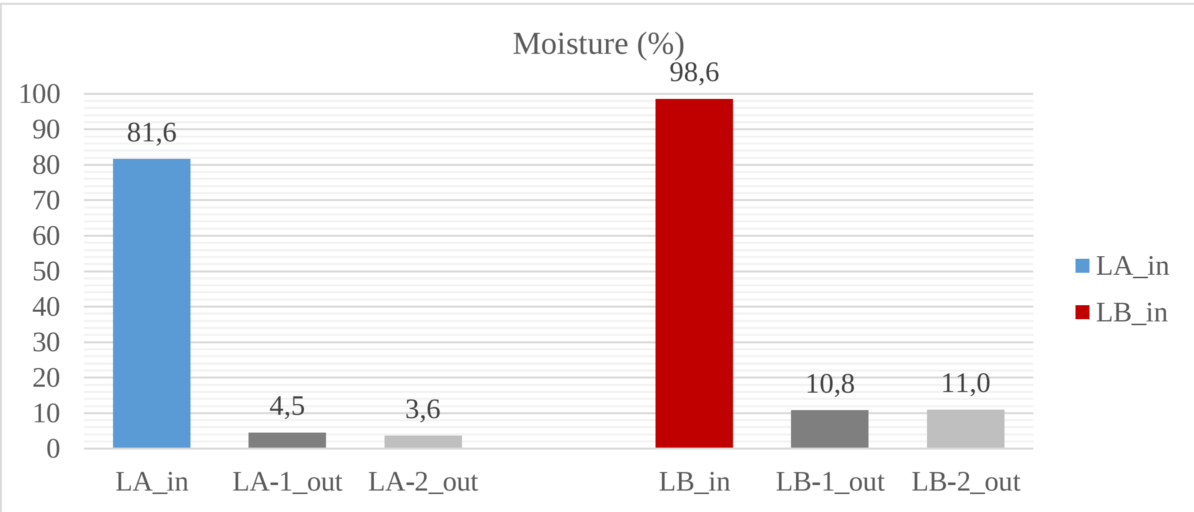
Throughout the experimental period, macrophyte regeneration was quantified in the experimental units and the control for subsequent analysis.

4. Results

4.1 Sludge dewatering

The initial characterization of the sludge LA_in has a moisture content of 81.6% and LB_in with 98.6%. Meanwhile, the results of the sludge dehydration after 65 days from the beginning of the experimentation can be seen reflected in graph 2, where it is observed that LA-1_out and LA-2_out obtained a final moisture content of 4.5% and 3.6% and the results of LB-1_out and LB-2_out presented a higher percentage of moisture with 10.8% and 11%, respectively. Contrasting with (Giraldi, y otros, 2009) which obtained a big decrease in sludge volume during the experimental research.

Figure 3: Moisture content



Source: Own elaboration, 202

In qualitative terms, the moisture content can be observed as the difference between the initial and final sludge with the following photographs**:**


LA_initial **LA_final**


LB_initial **LB_final**

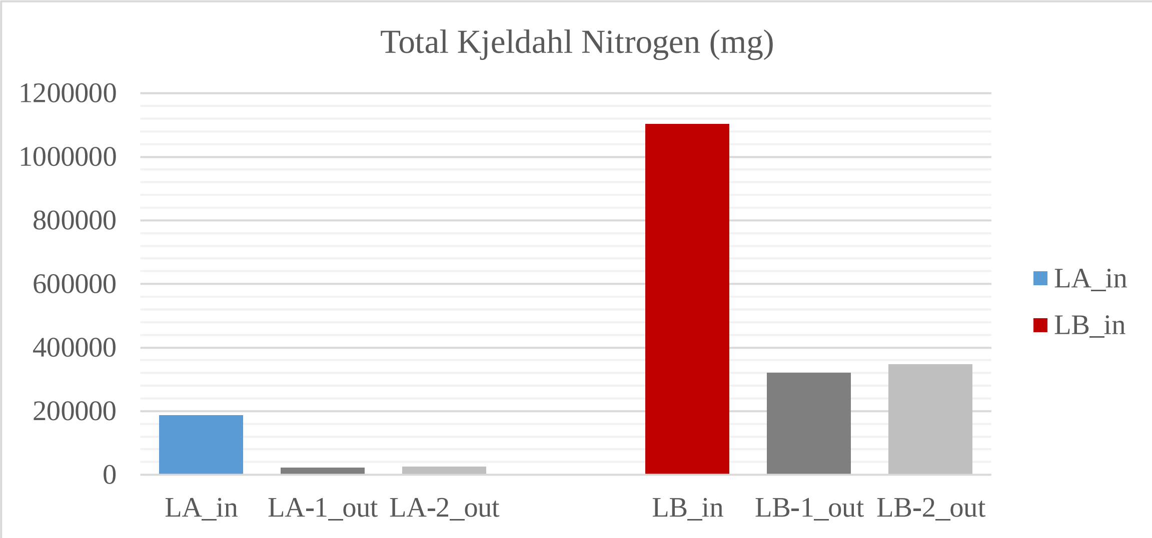
4.2 Nutrients

4.2.1 TKN – Total Kjeldahl Nitrogen

Considering that the sludge contains high values of TKN, a removal efficiency at the end of the experimentation of 88% and 87% for LA-1_out and LA-2_out and 71% and 69% for LB-1_out and LB-2_out respectively was obtained. According to (Fountoulakis, Sabathianakis, Krisotakis, Kabourakis, & Manios, 2017), Vegetation is known to play an important role in nitrogen removal in artificial wetlands due to plant uptake and microbial activity around the rhizome. It is well known that vegetation plays a crucial role in nitrogen removal in artificial wetlands due to the ability of plants to absorb nitrogen and the microbial activity present around their roots (Fountoulakis, Sabathianakis, Krisotakis, Kabourakis, & Manios, 2017).

Although LB presented a higher plant density at the end of the experiment, it did not achieve a higher removal rate compared to LA. However, the percentage of removal obtained can be considered satisfactory.

Figure 4: TKN results

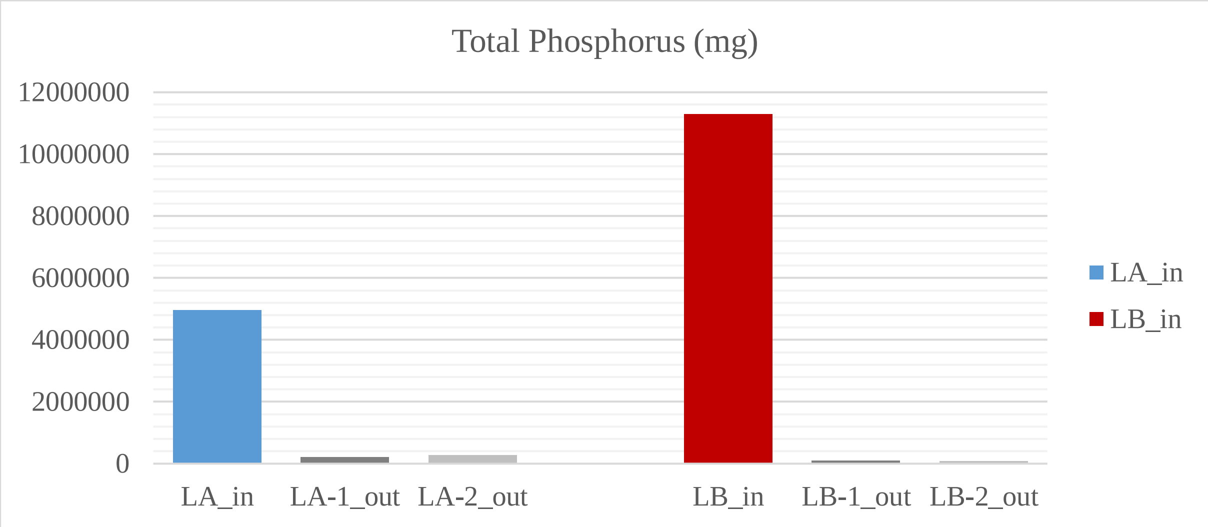


Source: Own elaboration, 2022

4.2.2. Total Phosphorus

The removal of phosphorus contained in the dewatered sludge at the end of the experiment was 96% and 94% for LA-1_out and LA-2_out and 98% and 99% for LB-1_out and LB-2_out. The removal efficiency was very good as it was above 94% for both treated sludges. Since phosphorus is no longer an inexhaustible resource, along with the higher cost of commercial fertilizers, many biological and chemical processes have been developed to recover nutrients from wastewater and sludge (Kleemann, y otros, 2015).

Figure 5: Total Phosphorus results



Source: Own elaboration, 2022

Therefore, constructed wetlands technique for sludge treatment is highly recommended to achieve the recovery of nutrients, mainly phosphorus and nitrogen present in the sludge.

4.2.3. Sludge stabilization

In the results of volatile solids obtained, the sludge with the highest amount of SV in the initial characterization is found in LB_in with 71.4% followed by LA_in with 27.6%.

As stated by (Uggetti, Ferrer, Llorens, & García, 2010) "a review of the state of the art". In the efficiency of several wetland facilities for sludge treatment, it shows the decrease in the concentration of volatile solids (VS) in the sludge, during the sludge treatment inside the wetlands, where it points out that it can achieve a reduction of VS of 25 to 30%, reaching final concentrations of VS between 40% and 50%. However, the reduction of volatile solids obtained in the experimentation is 7.8% and 9.4% for LA-1_out and LA-2_out and 3.7% and 2.4% for LB-1_out and LB-2_out respectively. Therefore, a total stabilization of the sludge was not achieved.

4.2.4 Regeneration and root growth

Table 3 represents the root growth on *Typha domingensis Persoon* (Cattail) in each reactor plus the control, measured in centimeters. The values indicate that the roots that were in the control showed good root growth, and the roots treated with the sewage sludge did not show the same behavior because they were in a denser environment and had difficulties to grow, but despite these difficulties, the plant in general was regenerating.

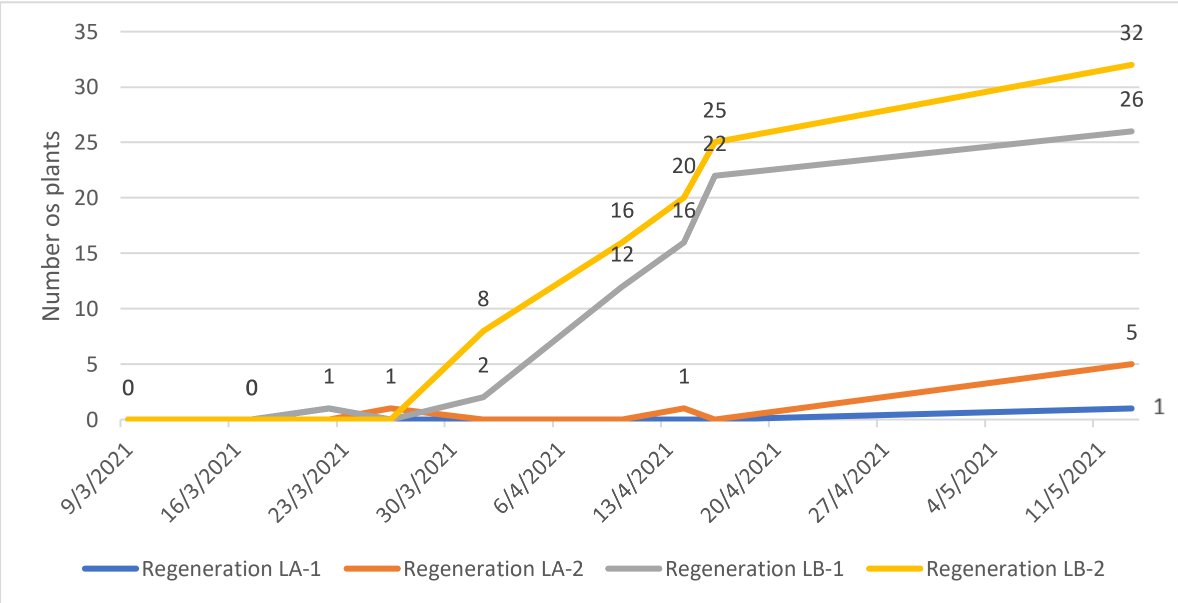
Table 3: Root grot¿wth

Period	LA-1	LA-2	LB-1	LB-2	Control
day	cm	Cm	cm	cm	cm
1	27	32	20	32	32
17	30	25	25	25	27
38	28.5	28.5	22.5	28.5	29.5

Source: Own elaboration, 2022

The results of *Typha Domingensis Persoon* regeneration density in the experimental units can be seen in Figure 6.

Figure 6: Regeneration of *vegetal species*



Source: Own elaboration, 2022

The difference in plant densities in each of the experimental units after 65 days of operation demonstrates the difference in moisture and nutrient content of each of the sludges at the start. The density of LB increased proportionally to the sludge feeding in the wetlands, the large amounts of water contained in the sludge, and the enormous amount of nutrients compared to LA. As (Vyzamal, 2005) indicates: the rapid increase in plant density could be justified by the presence of an excess of nutrients, which are mineralized and bioavailable by the bacteria present, thus understanding why there was a higher density in LB.

5. Conclusions

The implementation of vertical flow artificial wetlands for sludge dewatering is feasible since both sludges showed optimum results, obtaining a final moisture content in LA-1_out and LA-2_out of 4.5% and 3.6%, and in the results of LB-1_out and LB-2_out a higher percentage of moisture content was obtained with 10.8% and 11%, respectively.

In terms of nutrients, there were significant differences in the treatments for phosphorus removal, and no treatment differences were identified in nitrogen removal, due to the high concentrations and variations in the WWTP due to variations in concentration and flow rate.

A higher number of plant regeneration was obtained in sludge LB_1 and LB_2 with a total of 26 and 32 plants each, while there is a considerable difference with sludge LA_1 and LA_2 which only obtained a total of 7 and 8, respectively. This is because they are sludge samples coming from different technologies.

It can be concluded that, the vertical flow constructed wetland technique is a viable option for the dewatering and stabilization of sludge from wastewater treatment plants.

6. References

Cabero Ugalde, M. (2017). *Resumen Ejecutivo. Rentabilidad del reúso de Aguas residuales en riego agrícola -.* Tarija.

Centro de las Nuevas Tecnologías del Agua, F. (2021). *Guía técnica para la selección y tratamiento de aguas residuales.* Bolivia: Ministerio de Medio Ambiente y Agua.

Delgadillo, O., Camacho, A., Pérez, L., & Andrade, M. (2010). *Depuración de aguas residuales por medio de humedales artificales.* Cochabamba: Centro Andino parala Gestión y Uso del Agua .

Erazo Campos, O. (2004). Uso de la totora en la producción agrícola de. *Revista de Agroecología*. Obtenido de http://www.leisa-al.org.pe/

Fountoulakis, M., Sabathianakis, G., Krisotakis, I., Kabourakis, E., & Manios, T. (2017). Halophytes as vertical-flow constructed wetland vegetation for domestic wastewater treatment. *Science of The Total Environment*, 432-439. doi:https://doi.org/10.1016/j.scitotenv.2017.01.090

Giraldi, D., Masciandaro, G., Peruzzi, E., Bianchi, V., Peruzzi, P., Ceccanti, B., & Ianelli, R. (2009). Hydrualic and biochemical analyses on full-scale sludge consolidation reed beds in Tuscany (Italy). *Water Science and Technology*, 60 (5), 1209-1216. doi:https://doi.org/10.2166/wst.2009.418

Kacprzak, M., Neczaj, E., Krzysztof, F., Grobelak, A., Grosser, A., Worwag, M., . . . Singh, B. (2017). Sewage sludge disposal strategies for sustainable development. *Environmental Research*, 39-46. doi:https://doi.org/10.1016/j.envres.2017.03.010

Kleemann, R., Chenoweth, J., Clift, R., Morse, S., Pearce, P., & Saroj, D. (2015). Evaluation of local and national effects of recovering phosphorus at wastewater treatment plants: Lessons learned from the UK. *Resources, Conservation and Recycling*, (105)B, 347-359. doi:http://dx.doi.org/10.1016/j.resconrec.2015.09.007

Silva Tipantasig, L. G. (2019). *Diseño sistemas para el tratamiento de lodos mediante tecnologías de bajo coste para la EDAR Vall Dels Alcalans (Valencia).* Universitat Politècnica de València. Departamento de Ingeniería Hidráulica y Medio Ambiente, Valencia.

Stefanakis, A., Komilis, D., & Tsihrintzis, V. (2011). Stability and maturity of thickened wastewater sludge treated in pilot-scale sludge treatment wetlands. (19):6441-52. doi:https://doi.org/10.1016/j.watres.2011.09.036

Troesch, S., Lienard, A., Molle, P., Merlin, G., & Esser, D. (2009). Sludge drying reed beds: Full-and pilot-scale study for activated sludge treatment. *Water Sicence and Technology*, 60(5), 1145-1154. doi:https://doi.org/10.2166/wst.2009.388

Uggetti, E., Ferrer, I., Llorens, E., & García, J. (2010). Sludge treatment wetlands: A review on the state of the art. *Bioresource Technologý*. doi:https://doi.org/10.1016/j.biortech.2009.11.102

Uggetti, E., Llorens, E., Pdescoll, A., Ferrer, I., Castellnou, R., & García, J. (2009). Sludge dewatering and stabilization in drying reed beds: Characterization of three full-scale systems in Catalonia, Spain. *Bioresource Technology*, 3882-3890. doi:https://doi.org/10.1016/j.biortech.2009.03.047

Vyzamal, J. (2005). Horizontal sub-surface flow and hybrid constructed wetlands systems for wastewater treatment. *Ecological Engineering*, 478-490. doi:https://doi.org/10.1016/j.ecoleng.2005.07.010

Wu, H., Zhang, J., Ngo, H., Guo, W., Hu, Z., Liang, S., . . . Liu, H. (2015). A review on the sustainability of constructed wetlands for wastewater treatment: Design and operation. 594-601. doi:https://doi.org/10.1016/j.biortech.2014.10.068

Communication aligned with the Sustainable Development Goals