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Analysis of the impact on the sewage sludge treatment community by means of wetlands and vermicomposting and the production of fertilizer: systematic review

Análisis de la afectación en la comunidad de tramientos de lodos residurales por medio de humedales y vermicompostaje y la obtetención de fertifilizante: revisión sistemática

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Abstract

The sludge generated in wastewater treatment plants is an element of great importance due to the pollutants that constitute it and its potential impact on the environment. Therefore, it is important to investigate new technologies that can treat these biosolids with less impact and convert them into usable products, such as fertilizers. This article presents a review of the important aspects of the treatment of sewage sludge by means of wetlands and vermicomposting processes to obtain a material that can be applied to agricultural soil. Initially, information concerning the origin and composition of sewage sludge is presented. Subsequently, important aspects to consider in the treatment of sludge are mentioned, followed by an individual explanation of the treatments using wetlands and vermicomposting.

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Finally, the integrated treatment of wetlands and earthworms is described. At the end, conclusions and possible future research concerning the topic addressed in the article are drawn.
Keywords: sludge; vermiculture; swamps; compost; humus.

Abstract

El lodo generado en las estaciones depuradoras de aguas residuales es un elemento de gran importancia debido a los contaminantes que lo constituyen y su potencial impacto al ambiente. Por consiguiente, es importante investigar nuevas tecnologías que puedan tratar estos biosólidos causando un menor impacto y convirtiéndolos en productos utilizables, como por ejemplo fertilizantes. El presente artículo expone una revisión de los aspectos importantes del tratamiento de lodo residual por medio de humedales y procesos de vermicompostaje para obtener un material que pueda ser aplicado en el suelo agrícola. Inicialmente se presenta información concerniente al origen y composición del lodo residual. Posteriormente se mencionan aspectos importantes a considerar en el tratamiento de lodos y a continuación se explican de manera individual los tratamientos utilizando humedales y vermicompostaje. Finalmente se describe el tratamiento integrado de humedales y lombrices de tierra. Al final se establecen las conclusiones y posibles investigaciones futuras concernientes al tema abordado en el artículo.
Palabras clave: lodo; lombricultura; pantanos; abono; humus.

Introduction

Wastewater treatment processes generate considerable amounts of sludge Ignatowicz, (2017), thus becoming a surplus that must be treated and disposed of. Brix, (2017). The sludge contains various contaminants such as, pathogenic microorganisms, organic toxic compounds, inorganic substances, polymeric extracellular substances excreted by bacteria, recalcitrant organics and heavy metals. (Chen et al., 2016; Zhu et al., 2016; Wang et al., 2017; Hu y Chen, 2018; Hu et al., 2020).

The composition of sewage sludge causes this type of waste to require proper management, because it could affect surface water, soil and groundwater. Hu et al., (2020). There are conventional methods for sludge treatment based on concentration, drying, anaerobic digestion, which have high operating costs. Andrade et al., (2017)which have high operating costs and can also cause environmental Hu et al., (2017) and can also cause environmental impacts due to noise and emissions. Therefore, it is important to use natural and environmentally friendly processes such as artificial wetlands and vermiculture.

Sludge treatment by artificial wetlands does not use energy or mechanical equipment, neither does it require the addition of chemicals Brix (2017). Vermiculture is a promising technology in sludge reduction through a process known as vermicomposting, especially in small communities located in developing countries. Emamjomeh et al. (2017). Wetland-treated sludge is often used in soil as a fertilizer, as well as through vermicomposting. Chen y Hu, (2019)as well as through vermicomposting to stabilize the organic fraction of the sludge into humus material. Yadav et al. (2016).

Wastewater treatment plants generate sludge during primary (physical and/or chemical), secondary (biological) and tertiary treatments. Sludge is an aqueous, semi-liquid biosolid with a variety of colloids. Mendoza et al. (2010).

Biological treatment corresponds to the activated sludge system, which is a biochemical process through which wastewater purification is achieved using aeration tanks and artificial agitation for the development of a countless number of nitrifying organisms Orhon y Biotechnology (2015). In this way the organisms degrade the organic matter and the removal of nitrogen and phosphorus occurs. Dai et al. (2016). As a by-product of the treatment, residues called active sludge are obtained. Nascimento et al. (2020)which contain floccules that determine the properties of the sludge through size, shape, density and strength. Christensen et al. (2015). The composition of the sludge in its content of micro and macro elements depends on the chemical composition of the wastewater and the treatment technology used. Kiper et al. (2019).

The largest and most diverse group present in activated sludge is from the microbiological point of view, the sludge generated in treatment systems for domestic wastewater or domestic mixed with industrial waters possess a great bacterial diversity. The phylum proteobacteria dominate, followed by bacteroidetes and firmicutes, where in the latter Clostridium is the dominant genus, followed by Treponema, Propionibacterium, Sintrophus and Desulfobulbus. Nascimento et al. (2018).

In the analysis of 12 sludge samples collected from 5 sewage treatment plants across the United States, 43 different forms of human viruses were found, among which Adenovirus, Herpesvirus, Papillomavirus, Coronavirus, Klassevirus and Rotavirus DNA were identified. Mulchandani y Westerhoff (2016). In another study carried out on 10 sludge samples from 5 water treatment plants treating the water of a population of between 100,000 and 1,000,000 inhabitants, 43 different types of human viruses were observed through metagenomic studies, such as the respiratory viruses Coronarivus HKU1, Klassevirus and Cosavirus. Bibby et al. (2013). The SARS-Cov-2 virus, which caused a worldwide pandemic, has been detected in sewage sludge. Kocamemi et al., (2020).

Regarding heavy metal content, sludge from wastewater treatment systems possesses elements such as Zn, Pb, Cu, Cr, Ni, Cd, Hg and As, whose concentrations range from less than 1 mg/l to more than 1000 mg/l Huang et al. (2015).

Microplastics exist in sludge that could reach the environment when they are disposed in agricultural soil. In China, the existence of microplastics in sludge from 18 sewage treatment plants was investigated and it was observed that 59.6% of these presented a white color and 63% fiber as material represented by polyolefin, acrylic, polyethylene and polyamide Li et al. (2018).

Rarely is the wastewater only of domestic origin, mostly it also contains industrial wastewater and components from street and sidewalk washing when combined sewage systems are in place. Thus sewage sludge may also contain other elements in addition to organic matter, such as harmful toxins in the form of detergents, salts, hormone disruptors and toxic organics. Singh y Agrawal (2008).

Activated sludge may contain concentrations of pesticides depending on the type of industry. Ponce-Robles et al (2017) demonstrated through their research that high concentrations of pesticides can accumulate in industrial sludge, especially thiabendazole and pyrimethanil. The food and packaging industry in which high volumes of water are used for post-harvest treatment is a major source of pesticide contamination.

In Italy the study performed on samples collected from sludge coming from 35 sewage treatment plants to measure concentrations of nonylphenol, nonylphenol ethoxylates and phthalates showed, that the limits proposed by the European Union on substances to be used as fertilizers are sufficiently conservative to avoid negative effects on soil fauna Lamastra et al. (2018). Zoghlami et al. (2020) They concluded in their studies related to the treatment of semi-arid agricultural soil that the accumulation of organic matter and its mineralization improve soil structure and fertility in proportion to the dose of sludge applied. The study in an area over which sewage sludge was applied for 10 years showed that there was no increase in organic matter and there was an influence on biogeochemical parameters resulting in the total supply of P, partially N and micronutrients for maize crops. Melo et al. (2018). The residue can improve soil fertility. Tontti et al. (2017).

The presence of microplastics is a fundamental issue when considering the use of sludge in soil. Microsplastics are altered when there is treatment on the sludge, this becomes an unknown risk that can have a significant impact by accumulation in the soil and subsequent dispersal into lakes and marine ecosystems Li et al. (2018). The effectiveness of retention in sewage treatment plants depends on the density and particle size. Microplastics with a density greater than that of water are almost completely retained in the sludge during primary and secondary treatment. Nizzetto et al. (2016). When assessing the public health risks resulting from the application of activated sludge in residential areas, the potential interactions of contaminating chemicals with low levels of pathogens must be considered. An increased risk of infection can occur when allergic and non-allergic reactions to endotoxins and other chemical components irritate the skin and mucous membranes, which affect barriers to infection. Lewis et al. (2002).

Urra et al. (2019) concludes that sewage treatment plant sludge must be properly treated before being applied to agricultural soil, so as to minimize the introduction of contaminants and the risk of spreading antibiotic resistance. Before using sludge in agriculture, further studies are needed concerning the risk of mishandling, dispersal of sludge on the soil into water bodies due to climatic effects, additive and synergistic effects and toxicity. (Rastetter et al., 2017, p. 34).

Treatment systems called artificial wetlands are engineered systems that have been designed and constructed to utilize the natural processes related to vegetation in natural environments, soil and their association with microorganisms present in water treatment Vymazal y Březinová (2015). This wetland is also known as a reed bed system or sludge dewatering wetland and is composed of a porous medium in which emerging macrophytes are planted. Arroyo et al., (2018). The porous system has a sealed flushing zone composed of a filter bed of successive layers of stone, gravel and fractionated sand, within which processes such as the following occur (Magri et al., 2016)within which processes such as penetration, evaporation, transpiration and the production of leachates capable of being treated by additional wetlands also occur. Hu et al., (2019).

The stabilization process results from the synergistic action between plants, organic matter, microorganisms and the combination of other processes such as mineralization and humification Peruzzi et al. (2017).

The sludge treatment system causes the least environmental impact and is the one with the best cost-effective scenario for land application, compared to other treatments such as post-treatment composting, centrifugation with post-treatment composting and finally transport of the biosolid to a generalized treatment system Uggetti et al. (2011). In environmental impact, reference is made to a lower atmospheric impact in terms of COequivalent$_2$ emissions. Uggetti et al. (2012). In the evaluation of the level of contamination and potential ecological risk of heavy metals in the sludge, it is necessary to know the total concentration of heavy metals and their chemical form. Tytła y health (2019).

Plant species have a different effect on sludge. For example T. angustifolia and S. fluviatilis have a low performance in sludge volume reduction, while P.australis exhibits a high performance and better action in drying and mineralization Gagnon, Chazarenc et al. (2013). Species such as Phragmites australis Cav can absorb up to 23% of the total nitrogen, in general the plants through evapotranspiration reduce the volume of the sludge and improve filtration through the root system which stimulates microbiological activities. Korboulewsky et al., (2012). The saturated layer of wetlands favors transpiration and influences the volume of water and the mass of pollutants discharged. Gagnon et al., (2012). Phragmites austrlis and Typha species together with a wood chip filter media showed great benefits in sludge drying and mineralization, as well as no phytotoxicity and low heavy metal and pathogen content. Uggetti et al., (2012). Calderón-Vallejo et al. (2015) In addition, the performance of wetlands planted with Cynodon spp. in the treatment of sludge from septic tanks was investigated, finding a chemical oxygen demand removal efficiency of 71% and a total solids removal efficiency of 44%. The stabilization process in the sludge helps to immobilize heavy metals, which are retained in the sludge. Peruzzi et al. (2011)which are retained in fractions related to the stabilization of organic matter. Peruzzi et al. (2011).

In the evaluation of sludge dewatering performance and microorganism dynamics during the supply and rest periods, it was observed that total solids increased by 24-31% and volatile solids decreased by 43-47%, while total nitrogen kjeldahl and total phosphorus concentrations decreased Wang et al. (2020). If the wetland contains a piped aeration system, a better reduction of antibiotics such as oxytetracycline, tetracycline, azithromycin, sulfamethoxazole, as well as antibiotic resistance genes is achieved. Ma et al. (2019). Ventilation has a positive influence on the diversity and richness of the microbial community, which results in a good removal of pollutants such as organic matter in the water draining through the wetland, which in turn is less susceptible to being affected by the climate. Meng et al. (2020). Correlation analysis between antibiotic concentration and antibiotic resistance genes in the bottom and top layer of the wetlands indicate a significant correlation between roxithromycin, azithrocin and MRSA abundance. Ma et al. (2019). During the period of sludge supply in wetlands there may also be removal of antibiotic resistance genes. Ma et al. (2020). Micropollutants may be present in sewage sludge. These are mostly found on the upper surface of the wetlands or are diffused throughout the depth of the filter material, as is the case of xenobiotics. Maurer et al. (2020)The presence of plants promotes microbiological diversity and thus antibiotic removal and sludge stabilization, with the predominant bacterial community being Proteobacteria, Bacteroidetes and Firmicutes, while the dominant genera are Thiobacillus, Dechloromonas and Pseudomonas. Wang et al. (2019).

Uggetti et al. (2012) concluded in their research that the sludge from a wetland is close to being a stable end product and the concentration of heavy metals and fecal bacteria meet the legal permissible limits for land application.

Application of Vericomposting in the Treatment of Sewage Sludge from Wastewater Treatment Plants

Vermicomposting is a mesophilic process to stabilize organic matter using the joint action of microorganisms and earthworms under aerobic conditions (Xie et al., 2016). During this process, earthworms feed, grind and digest organic wastes with the help of aerobic and anaerobic microflora, leaving a moist and microbially active final material. (Maboeta et al., 2003). Worms increase the surface area of any material and make it more favorable for microbial activity and decomposition. (Bhat et al., 2018). The earthworm Eisenia fetida can convert household solid waste and sewage treatment plant sludge into compost of very good and acceptable quality . (Amouei et al., 2017). At the beginning the biomass and fecundity of the earthworms increases, but later decreases due to the unavailability of appropriate food, which shows that quality and abundance of food directly affect the biological parameters of the system. (Yadav et al., 2015). In investigations of the action of earthworms on granulated dehydrated sludge, an improvement in microbial activity and biomass was observed, with rapid decomposition and final products with low levels of bacteria and eukaryotic densities, compared to the non-addition of earthworms. (Fu et al., 2016).

Vermicomposting has been practiced in Poland since 2014 with sewage sludge from the Zambróv water treatment plant, where research showed that the use of Californian earthworm provides good mineralization and humification, thus complying the vermicompost with local regulations and is a valuable mineral-organic fertilizer (Boruszko, 2020). In a comparative study between composting and vermicomposting of sewage sludge, it was determined that after two initial thermophilic pre-compostings, vermicomposting achieved the best and most homogeneous final product. (Hanc y Dreslova, 2016). In addition, it has been shown that with vermicomposting the concentration of the regulator kinetin in plant growth is twice as high as with vermicomposting. (Rékási et al., 2019). On the other hand, mixing sewage sludge with garden waste and using vermicomposting processes with variations in their operation phases such as the addition of liquid fertilizer, recirculation of the generated leachate, addition of mature vermicompost and ventilation, proves to be highly positive in each case, accelerating the decomposition of organic material in comparison with traditional composting. (Cincin et al., 2019).

The earthworm E.andrei has a great ability to degrade previously composted sewage sludge by reducing microbial biomass such as bacteria and fungi, which also demonstrates that the composting-vermicomposting combination can be a good alternative for the management of this type of biosolids (Villar et al., 2016). The combination of organic waste subjected to vermicomposting and inorganic waste inoculated with treated wastewater results in a vermicompost rich in N,P,K, which can be used in the production of ornamental plants. (Karimi et al., 2017).

Over the years the concentration of heavy metals has been analyzed in the vermicompost made from the sewage sludge of the wastewater treatment plant in Zambrów, Poland, the results of which show that they are below the maximum permissible limits concerning fertilization and use in crops. (Boruszko, 2016).

Integration of Wetlands and Vermicomposting for Sewage Sludge Treatment

Artificial wetlands and vermicomposting are two processes that can be used for the treatment of sludge from sewage treatment plants, having the benefit of integrating both technologies. Worms can improve sludge dewatering and stabilization in wetlands planted with P. australis, in addition to decreasing E. coli and volatile fatty acids and converting the final product into a good fertilizer. Hu y Chen, (2018). Earthworms improve sludge stabilization dramatically in the accumulated sludge and increase evapotranspiration. Chen et al., (2016). Although worms can decrease the nutrient content, they have a positive effect on the heavy metal content by decreasing for example the bioavailability of Cd and Cr in wetlands. Chen y Hu, 2019, Hu et al. (2020). There is an improvement in the removal of TN and TP in wetlands due to the absorption of Typha orientalis and the biological effect of T. tubifex. Kang et al., (2017).

Conclusions

Due to population growth and thus the need for territorial expansion, there is a need to implement new wastewater treatment plants, which also leads to an increase in the generation of sewage sludge, thus becoming a waste requiring treatment. The current systems for the treatment of this sludge entail construction, energy, operation, mechanical costs and impacts due to atmospheric emissions and noise. For this reason it is important to develop and research new low-cost technologies with less impact on the environment, such as artificial wetlands and vericomposting.

Wetlands and vermicomposting, when used separately, demonstrate high efficiencies in the removal of contaminants such as pathogens and heavy metals from the sewage sludge, also achieving the respective dewatering and mineralization. Both are low-cost technologies in construction and operation.

Constructed wetlands depend on climatic conditions for a correct and rapid stabilization of organic matter. Within these, the microbiological and biochemical parameters vary during the sludge supply and settling stages, and it is therefore essential to consider the duration of the process at the time of use. Drying is essentially due to evapotranspiration carried out by plants.

Vermicomposting in sewage sludge leaves a product with good characteristics to be used as fertilizer. The worms through their digestive system process the organic matter and release a product rich in nutrients.

The use of earthworms in artificial wetlands provides an additional and effective aid when dewatering and stabilizing the sewage sludge for use in agricultural soil, so this combination should be studied in greater detail focusing on the removal of contaminants such as antibiotics, antibiotic resistance genes, heavy metals, microplastics, emerging pollutants, viruses. In the latter, the Sars-cov-2 virus and its permanence in the sewage sludge after going through the treatment process and applied as fertilizer should be the object of study.

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