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Assessment of the treatment, production and characteristics of WWTP sludge in Andalusia by multivariate analysis

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ABSTRACT

Agricultural recovery is the primary option for the final destination of sewage sludge, which must be properly treated, stabilized and sanitized. However, these processes are occasionally eliminated or not carried out properly for economic reasons or due to the design and size of the treatment plant. In this study, 62 samples of sewage sludge (21 and 41 samples from Seville and from Huelva, respectively) were characterized. Variable annual sludge production and equivalent inhabitants are virtually proportional (related by a potential power function of 0.9134). The results were evaluated through multivariate statistical analysis in order to assess the operability status of the WWTPs and the final quality of the sludge generated in the processes. Principal components analysis provided information on two separate groups for the bulk of waste water treatment plant (WWTPs) analyzed: (1) a nickel group, where the samples showed outliers above 50 mg/kg with respect to other WWTPs; and (2) the group where total nitrogen, organic matter and total potassium (K_2O) showed abnormally high values. Linear discriminant analysis models allowed the detection of WWTPs that used inadequate treatments but where geographical area and number of equivalent inhabitants were not significant.

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1. Introduction

The rapid growth of industrialization and urbanization in the 21 st century has resulted in the generation of huge volumes of wastewater which must be appropriately treated in order to prevent environmental and human health risks. In this regard, Council Directives 91/271/EEC and 98/15/EEC concerning urban wastewater treatment establish that all urban agglomerations with a population equivalent (p.e.) of more than 2000 should have a wastewater treatment system (WWTS) in compliance with discharge limitations. This obligation, and the increased awareness of the need to protect water resources, has led to significant public investments at the European, state, regional and local levels for the design, construction and maintenance of wastewater treatment plants (Wieland, 2003).

Although the treatment of wastewater is beneficial for the environment, the process generates an unmanageable quantity of sludge amounting to millions of tons (Aparicio et al., 2009). Managing this sludge is a major concern for wastewater treatment plants (WWTP), as it accounts for 60% of plants' total capital costs (Di Iaconi et al., 2010). Furthermore, sludge production in Europe has grown from 5.5 million tons of dry solids in 1992 to 8 million in 1998 and 10 million in 2007 (Fytili and Zabaniotou, 2008) in recent decades, as well as disposal costs (estimated at between 350 and 750 euros per ton of dry solids) (Di Iaconi et al., 2010). Due to the increasingly stringent legis-

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lation on sludge disposal, it is necessary to develop an environmental and economically viable management process adapted to the specific areas where sludge is generated (Uggetti et al., 2012; Boller, 1997), thus limiting the available management methods (Pilli et al., 2011).

A wide variety of sludge treatment technologies related to final disposal practices and the size of WWTS are used in the EU-27, with anaerobic and aerobic digestion appearing to be the most common methods in these countries. Anaerobic digestion is most widely used in plants with a capacity of >50,000 equivalent inhabitants (E.I.), whereas aerobic digestion is the prevailing technology in less populated regions (Kelessidis and Stasinakis, 2012). Among the proposed aerobic methods, composting is an interesting alternative as it valorizes the stabilized sewage sludge for use as an organic amendment. Moreover, the proper aerobic management of sludge (the composting process) presents numerous environmental advantages. These include the recovery of resources from the sludge such as organic matter and nutrients, as well as the improvement and regeneration of agricultural or devastated soils (Epstein et al., 1978; Doublet et al., 2010). In fact, agricultural use has become the principal disposal method for sewage sludge. Specifically, 81% of produced sludge is used in agriculture, while 7% is incinerated, 7% is landfilled and 5% is used for other purposes such as forestry, silviculture or land reclamation, among others (MAGRAMA, 2012). However, the metal concentration of sewage sludge may be under the limit established be the Royal Decree 506/2013 on fertilizing products. Metals occurring in excessive amounts are extremely harmful to the environment. Toxicity of individual elements introduced along with compost to soil can cause changes in its fertility, reduce the prolificacy and quality of plants. It can also lead to the contamination of surface and groundwater by infiltration of metals (Ignatowic, 2017; Bouriouga et al., 2015).

Moreover, the selection of the most suitable management method is conditioned by the characteristics of the sludge, but these characteristics depend on the origin of the sludge and the treatment in plant (Las Heras, 2009). Small urban agglomerations are therefore calling for actions to reconcile the difference between the required treatment limits and the economic viability of the process. In that sense, the coordination of sludge management strategies in areas encompassing small urban agglomeration could be an interesting option in order to ensure the viability of these processes.

The aim of this study is to compile information on the operation and management of WWTPs in the provinces of Seville and Huelva (Andalusia, Spain) to assess the operability status of the WWTSs as well as the generation, treatment, management and final disposal of the sludge generated in the processes. Authors such as Tognetti et al. (2007a,b) used the PCA multivariate approach to assess the management and stabilization of the composting process and final products. In our study, the PCA provides information on a group of WWTPs that treat sludges of similar characteristics and whose processes result in the poor stabilization of organic matter and a product that does not comply with the legislation on the use of sewage sludge in agriculture. The main conclusions drawn from this information may be of interest as they can be extrapolated on a wider scale.

2. Materials and methods

2.1. Data collection: field work

The provinces of Seville and Huelva were selected to assess the operation and management of WWTPs based on an inventory provided by the Andalusian Water Agency (now known as the Environment and Water Agency and integrated into the Environment and Water Agency of the Regional Ministry of the Environment and Territorial Planning). To review and update the available information, we visited the plants over a 4-month period during which time information about the WWTPs (66 in Seville and 68 in Huelva) was compiled using a standard form and samples of dehydrated sludge were collected for purposes of physico-chemical characterization. Information regarding the WWTP (operational status, population equivalent treatment capacity, characterization of input effluent and process description); a description of the sludge treatment line; production data, characterization of discharge sludge; sludge management; and other additional information were collected.

As regards the operational status of the WWTPs, we considered not only their operational–non operational status, but also those which are in the bidding process, have been adjudicated or are under construction, since the implementation of Directive 91/271/EC, as amended by Directive 98/15/EC, has meant that many WWTPs can be defined according to these operational statuses.

As concerns the assessment of sludge treatment lines, Table 1 shows the number of WWTPs for which information on each of the selected items is available: thickening, stabilization, chemical conditioning and dewatering.

To organize the data contained in the inventory, the two provinces were divided into six geographical areas (management units; MU) according to Decree 310/2003, which establishes the size of urban agglomerations for the treatment of wastewater in Andalusia. Each plant was assigned an identification code indicating the province, the management unit and a serial number within each unit.

2.2. Characterization of WWTP sludge

The sludge from the WWTPs was characterized according to the size of the population served and classified as category 1, 2 or 3 depending on whether the population equivalent was ≤10,000 E.I.; 10,000–100,000 E.I. or ≥100,000 E.I., respectively. The number of sewage treatment plants classified in category by population equivalent for both provinces is also shows in Table 1.

All sludge samples were analyzed in accordance with the Standard Methods of the APHA (Apha-Awwa-Wpcf, 2001) and/or the test methods for the examination of composting and compost developed by the US Department of Agriculture and the US Composting Council (Thompson et al., 2001) depending on the parameter. Sludge quality was characterized in terms of B1 agronomic variables (% except pH): pH, moisture (%), organic matter (OM, %), total nitrogen (N_{Total}, %), potassium (K_2O, %) and total phosphorous (P_2O_5, %); and B2 heavy metals (mg/kg): zinc (Zn), copper (Cu), nickel (Ni), cadmium (Cd), lead (Pb), mercury (Hg) and chromium (Cr), which are the principal elements restricting the use of sludge for agricultural purposes.

Moisture and OM: Standard Methods 2540B and 2540E, respectively, N_{Total}: a method based on the 4500-Norg B of Standard Methods, AN. pH was analysed using a pH-meter model Crison 20 Basic (Apha-Awwa-Wpcf, 2001). K_2O and P_2O_5 were analysed according to Thompson et al. (2001).

The heavy metal concentration was determined by a Perkin-Elmer AAnalyst 100/300 flame atomic absorption spectrometer. An air–acetylene mixture, whose proportion depends on the metal to be analysed, was used as a combustion fuel.

2.3. Data treatment using multivariate analysis

Multivariate analysis was performed using two algorithms: principal components analysis (PCA) and linear discriminant analysis (LDA). PCA was performed to explore the potential of the analytical data and evaluate the main characteristics

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