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A transport cost-based optimization for recycling of municipal sludge through application on arable lands

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ABSTRACT

Agricultural use of sludge is a beneficial alternative for sludge handling and recycling which may improve soil fertility through providing organic matter and nutrients. This study focuses on sludge application scheduling for suitable arable lands. Ankara (Turkey) was the study site. A screening procedure and buffer zone application were conducted to eliminate the arable lands not suitable for sludge application. ArcGIS was used for spatial analysis. Then a transport cost-based optimization model was employed to determine the lands that would be receiving sludge in a management period of 2013 to 2022. The spatial analysis by ArcGIS indicated that 75% of the total non-irrigated arable lands in Ankara were not appropriate for sludge application. Optimization results showed that only 17% of the suitable lands could receive sludge application for the conditions considered in this study. Average costs for sludge transportation in the management period were $84,855/year, $77,299/year, and $62,349/year for truck capacities of 10, 16 and 24 t, respectively. Total sludge transportation costs decreased for higher truck capacities. Sensitivity analysis indicated that transportation costs and the area of suitable lands receiving sludge were sensitive to sludge application dosage, application frequency, travel distance, and unit fuel cost escalation.

1. Introduction

Industrial development, population growth, improvements in life style, and agricultural activities are among the factors leading to higher wastewater production. Consequently, capacities and the number of wastewater treatment plants have increased. An inevitable result is the rise in the production of sludge, which is the semi-solid residue generated during biological wastewater treatment (US EPA, 1993). Although "biosolids" has been used to refer to sewage sludge that has been stabilized and disinfected to meet the regulatory limitations for uses such as fertilization or soil amendment (UNHSP, 2008; US EPA, 1999a), "sludge" term will be used throughout this study. About 10 million tons of dry sludge was produced in the European Union Member States in 2003 to 2006 (European Commission, 2010). In U.S., nearly 6.2 million tons of dry sludge is produced annually in wastewater treatment plants (Kargbo, 2010). ENVEST (2005) estimates that sludge amount in Turkey will reach more than 1 million tons of dry solids per year by 2020.

Due to the recoverable resources in sludge, restrictions on landfilling of sludge have been enforced in many countries (US EPA, 1993; European Commission, 2010). As a result, rather than landfilling, recycling of sludge through use for beneficial purposes is the current trend in sludge management (Escala et al., 2013). A beneficial use of sludge is to make use of its nutrient content (Libhaber and Orozco-Jaramillo, 2012; Ribeiro et al., 2010; UNHSP, 2008). Sludge includes readily available macronutrients (e.g. N and P) and micronutrients (e.g. B, Cu, Fe, Mn, Mo, Zn) required for plant growth (Lu et al., 2012). Although the ratio of these constituents may not be equivalent to that of a commercial fertilizer, sludge can still be used for agricultural purposes especially when it is supported with additional fertilizer to meet the nutrient requirements of cultivated crops (Tchobanoglous et al., 2003). Although land application improves plant yields and amends the organic content of soils, care should be taken as well to control potential soil contamination by heavy metals, organic contaminants and pathogens that may be present in sludge (Singh and Agrawal, 2008; US EPA, 1999b).

Agricultural use of municipal sludge has been practiced in many countries. According to Laturnus et al. (2007), 41% and 36.4% of sludge produced in U.S. and European Union Member States, respectively, are used in agricultural activities. Escala et al. (2013) reports the percentage of sludge reused in agricultural applications in Europe as 53% (Escala et al., 2013). In recent years, use of sludge

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Fig. 1. Province borders of Ankara.

as fertilizer or soil conditioner is taking attention in Turkey as well due to high nutrient content of sludge and poor organic matter content of most soils in Turkey (UNHSP, 2008). Yet, there is strong opposition for land application of sludge in Turkey due to environmental and soil quality concerns. In this study, sludge application scheduling in arable lands was studied based on transportation costs. Through sludge application by a given frequency, repeated application on a given land was avoided which may also decrease the risk of subsurface or soil contamination. Ankara was the study site. First, suitable non-irrigated arable lands within the provincial border of Ankara were determined through spatial analysis guided by a screening process. In screening of the lands, slope, land use capability, soil characteristics, proximity to various locations such as residential areas, water courses and water bodies, railways, sand plains, and inland marshes were considered. Then an optimization model was applied to select the arable lands in which the sludge of Ankara Central Wastewater Treatment Plant (ACWWTP) could be applied with the minimum transportation costs in the management period of 2013 to 2022. Transportation cost is important for the management of sludge application on land as the unit gas prices in Turkey rank among top 5 in the world (GlobalPetrolPrices.com, 2014).

2. Methodology

2.1. Ankara central wastewater treatment plant

Ankara is the capital city of Turkey. It is situated at 38°44′–40°45′N and 30°49′–33°52′E (Fig. 1). In 2012, population of Ankara was 4,965,542 (TUIK, 2013a). Climate in Ankara is of continental-Mediterranean type. In winter, it is very cold with little precipitation. In summer, it is hot with almost no rainfall (Karaca et al., 1995). Average ambient temperatures vary in the range of 0.3–23.5 °C. Average total precipitation during May reaches to 51.2 kg/m^2, nearly five times greater than that for August.

Wastewater produced by 95% of the population in Ankara is treated in wastewater treatment plants (TUIK, 2013b). There are 10 wastewater treatment plants in service. Among those ACWWTP

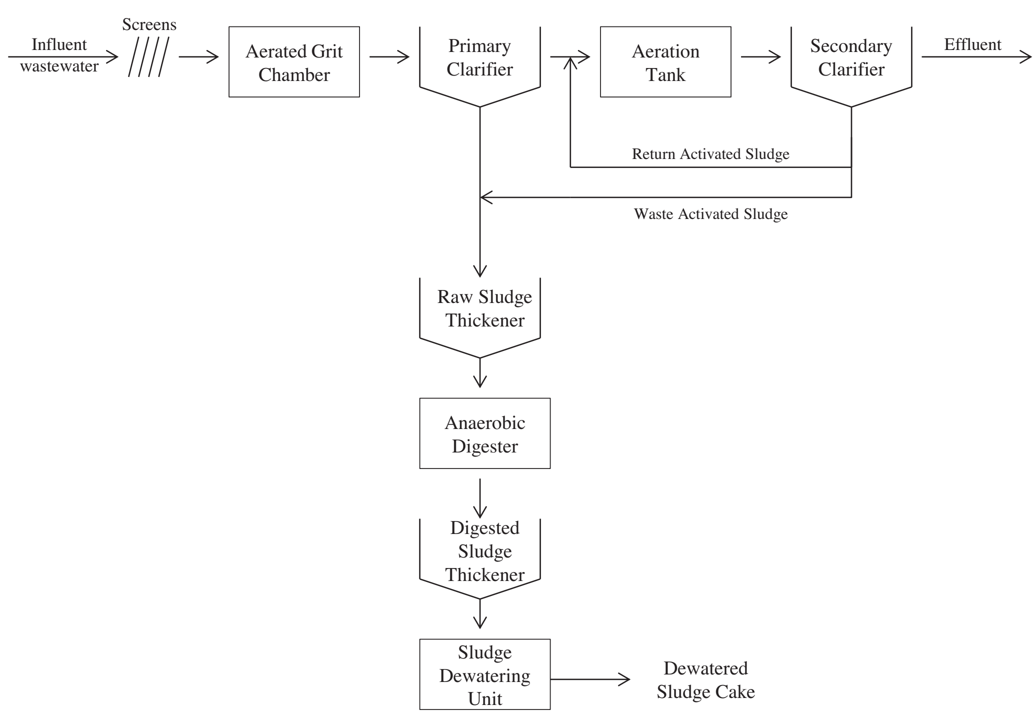

Fig. 2. Treatment process flow diagram of Ankara Central Wastewater Treatment Plant (ACWWTP).