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Two-stage vertical flow multi-soil-layering (MSL) technology for efficient removal of coliforms and human pathogens from domestic wastewater in rural areas under arid climate

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ABSTRACT

This paper investigates the removal efficiency of organic matter, nitrogen, phosphorus, coliforms and pathogens from rural domestic wastewater in a two-stage vertical flow multi-soil-layering (MSL) system. The effects of wastewater quality, season and arid climate conditions on pollutants removal efficiency by the system were examined for one year. The experimental setup included two similar MSL systems composed of two layers: soil-mixture-layers (SML) and gravel permeable layers (PL) that are arranged in a brick like pattern. The applied hydraulic loading rate was 1000 L m^{-2} day^{-1}. Results showed that most of the physicochemical contaminants elimination occurred while the wastewater percolated through the first MSL stage. The second stage demonstrated an improvement in the reduction of all pollutants, especially fecal bacteria indicators and pathogens. The mean overall removal rates performed by the two-stage MSL system were 97% for TSS, 96% for BOD_5, 91% for COD, 96% for TN and 95% for TP. For bacterial indicators, the combination of two-stage MSL system achieved high log removals between 2.21 and 3.15 log units. Contaminants reduction processes in MSL technology are more dependent on internal than external environmental factors. The effectiveness of the two-stage MSL system to treat domestic wastewater was strongly influenced by wastewater quality. Significant relationships between influent contaminants level and their removal efficiency were found. The efficiency of MSL technology to reduce contaminants is not sensitive to season and air temperature fluctuations. This is due to the capacity of MSL system materials to withstand the air temperature variation, which highlights one of the advantages of MSL's technology. Wastewater quality is the most important factor affecting the removal of contaminants in the MSL, which could be a critical parameter to considered when designing MSL system. Two-stage MSL system achieved a high treated wastewater quality amenable for treated wastewater reuse in agriculture recommended by Moroccan code of practice. Therefore, the combination of two-stage vertical flow MSL system could be considered an efficient and promising domestic wastewater treatment solution in arid countries to promote environmental protection and wastewater reuse.

1. Introduction

Developing sustainable solutions for rural sanitation is a serious global issue that has received limited attention until recent years (PNAR, 2013). In rural areas throughout Morocco, sanitation and wastewater treatment are significant environmental challenges. According to the National Program of Rural Sanitation, about 14.6 million people live in rural communities, and only 11% have access to sanitation facilities (PNAR, 2013). The classical technologies, such as activated sludge, are very expensive, maladapted to rural conditions, and require a trained staff for operation and maintenance. Therefore, wastewater is usually poorly collected and directly discharged in the environment, causing significant environmental and health risks (Moubarrad and Assobhei, 2007; Hajjami et al., 2013). In rural areas of Morocco, conventional centralized sanitation systems are impractical due to the topography and long distances between rural villages and urban cities. Moreover, rural domestic wastewater is characterized by high concentrations of organic matter, nutrients (nitrogen and

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phosphorus), coliforms and pathogens. Additionally, wastewater production in rural areas has increased in recent years thanks to the development of the Rural Water Supply Project. Through this project, access to potable drinking water increased from 14% in 1995 to over 91% in 2015.

Diverse methods for natural domestic wastewater treatment have been tested in decentralized areas, such as lagoons, wetlands and sand filters. Lagoon systems, in particular, were popularly used for a large-scale community in Morocco (Kouraa et al., 2002; Bdouri et al., 2009). However, these technologies presented numerous drawbacks, such as high area demand, evaporation of huge quantities of valuable water, the increase in inorganic salt content, and the generation of significant odor problems (Bdouri et al., 2009). The treatment performance was also dependent on season and climatic conditions, making lagoon systems unreliable (Bdouri et al., 2009). Wastewater treatment efficiency by constructed wetlands (CWs) must consider the climate. Under arid climate, characterized by high temperature, the evapotranspiration is important and huge quantities of valuable treated water can be lost causing an increase of the inorganic salt content in treated water (Mandi et al., 1993; Masi and Martinuzzi, 2007). Sand filters were used for such Moroccan rural areas (Guessab et al., 1993). However, this system showed several drawbacks, such as rapid clogging, and required frequent maintenance operations (Leverenz et al., 2009).

In recent years, a new wastewater treatment technology called the multi-soil-layering (MSL) system has been introduced and successfully tested for domestic wastewater treatment in Japan (Masunaga et al., 2007), Thaïland (Luanmanee et al., 2002), USA (Pattnaik et al., 2007), China (Luo et al., 2014) and Taïwan (Ho and Wang, 2015). The investment costs of MSL technology are very low compared with the lagoon systems, CWs, and sand filters. The MSL system is characterized by occupying a small area, a high hydraulic capacity, simple maintenance, no frequent clogging, the application of high organic and hydraulic loading rate, no energy requirement and the effective life was estimated to be longer than 20 years (Chen et al., 2009). Therefore, the MSL system has the potential to become a sustainable domestic wastewater treatment option in developing countries.

Recently, the MSL system was tested at laboratory scale in Morocco using local materials. The results from this experiment have proven to be very encouraging in potential large-scale use (Latrach et al., 2015; Latrach et al., 2016). The decision to use MSL technology must consider the climate. The MSL system has proven to be a very efficient method for wastewater treatment under tropical and temperate climate conditions (Luanmanee et al., 2001, 2002). Nevertheless, no prior study has tested this technology under an arid climate, characterized by temperature fluctuations, high evaporation rate, and long dry spells. The scale up of this technology should be adopted properly, based on local conditions of rural areas, taking into account their highly concentrated effluent and their climatic conditions. Wastewater quality and seasonal temperature are important factors that influence the treatment efficiency of the MSL systems.

The MSL system has demonstrated its ability to remove a wide variety of contaminants, including organic matter and nutrients (Latrach et al., 2015). However, bacterial pathogens are also important constituent of domestic wastewater and their control is one of the fundamental wastewater treatment objectives. Removal of pathogens from domestic wastewater should be one of the main preoccupations when establishing a wastewater treatment plant. Except our last reports, few studies have addressed the disinfection effectiveness of MSL technology (Latrach et al., 2015; Latrach et al., 2016). Furthermore, mechanisms involved in pathogens reduction by MSL system and factors influencing their removal efficiencies are not fully investigated. Therefore, the examination of MSL system performances under field conditions in terms of water sanitation is necessary for better design and operation of the MSL system. Mechanisms involved in bacteria removal from wastewater treatment technologies based on filtration process like MSL system, sand filters and CWs are diverse and complexes including filtration, adsorption and microbial inactivation (Stevik et al., 2004). Their effects depend on several factors such as wastewater composition, intrinsic physicochemical conditions and climate variations (Stevik et al., 2004). The relationship between influent bacteria concentration and their removal was demonstrated in CWs (Tunçsiper et al., 2012). In addition, previous experiments have investigated the relationship between nutrients levels in wastewater and bacteria indicators removal. Results from Winward et al. (2008a), showed an improvement of bacteria concentration in treated wastewater as the content of organic matter, suspended solids and nutrients increased. Physicochemical conditions including pH and dissolved oxygen are also critical factors influencing on bacteria survival and inactivation in natural systems (Gammack et al., 1992; Pundsack et al., 2001; Winward et al., 2008a, 2008b; Headley et al., 2013). There are several experiments at present evaluating the relationships between temperature and bacteria indicators removal in natural wastewater treatment methods (Stevik et al., 2004). Studies carried out in CWs have reported significant correlations between temperature and bacterial indicators removal (El Hamouri et al., 1994; Winward et al., 2008b). The effects of all these cited parameters remain to be elucidated in MSL system. The present study is designed to evaluate the efficiencies of two-stage MSL technology for treating rural domestic wastewater under arid climate conditions, paying special attention to coliforms and human pathogens removal. The effects of wastewater quality, season and temperature on the two-stage MSL system performances were investigated.

2. Material and methods

2.1. Study area and experimental conditions

The study was conducted in a wastewater treatment pilot plant in Talat Merghen village (Tahanaout commune) in the Al Haouz province approximately 40 km south of Marrakech, Morocco. In this area, most households have livestock in their compounds. The climate is Mediterranean arid. Average temperature ranges from 16.6 °C in January (coldest month) and 36.6 °C in July (warmest month). In July, the temperature reaches its highest level showing extreme value (44.6 °C); while, its lowest level is recorded in January (4 °C). The average of annual rainfall is about 340 mm. Domestic wastewater from eight households with 72 inhabitants was collected by a holding tank with a volume of 1000 L and used to feed the two-stage MSL pilot plant. Wastewater treatment plant contains a settling tank and two-stage MSL system pilots. Primary effluent from the settling tank was used as the influent of the MSL system (Fig. 1). Two similar MSL systems were built in cylindrical plastic boxes measuring 65 cm in height and 40 cm in diameter. The two-stage MSL systems was composed of soil mixture layers (SML) and gravel permeable layers (PL) that were arranged in a brick-layer like pattern (Fig. 1). The SML was comprised of local sandy soil, charcoal, sawdust and iron metal on a dry weight ratio of 70%, 10%, 10% and 10%. Physicochemical characteristics of soil were reported in Table 1, which also summarized the mineral composition determined by X-ray fluorescence using a portable XRF analyzer (Olympus NDT, Waltham, USA). The hydraulic loading rate (HLR) was 1000 L m^{-2} day^{-1}.

2.2. Sampling and analyses

Samples from MSL pilot's influent and effluent were collected at almost the same time every two weeks during a period of one year (from July 2014 to June 2015). Water samples were analyzed for physiochemical and bacterial parameters according to normalized methods (AFNOR, 1997; APHA, 2005; Moroccan Standards, 2006; Rodier, 2009). Samples were kept in sterile laboratory glass bottles and transported to the National Center for Research and Study on Water and Energy at the Cadi Ayyad University of Marrakech, for immediate