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Research article

Descriptive and multivariate analyses of four Tunisian wastewater treatment plants: A comparison between different treatment processes and their efficiency improvement

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A B S T R A C T

This study was undertaken to evaluate the performance of four wastewater treatment plants/processes over a 4 year period. The wastewater flow evolution, energy consumption, and quality indicator parameters (BOD_5, COD and TSS) at the inlet and outlet sites of the plants were determined. In comparing three domestic WWTPs with different wastewater treatment processes, the multivariate analyses (RDA and ANOVA) showed that although the Agareb plant received the highest pollution load, it displayed a high level of removal efficiency especially for COD, BOD, TSS, TKN and NH_4^+. It also revealed that the fluctuations in the wastewater composition and its contamination by varied industrial discharge could lead to the decrease in performance of the WWTP with activated sludge process as observed for the Southern Sfax plant. However, the electrolysis of the outlet water of Southern Sfax plant showed a significant improvement in COD removal.

1. Introduction

Wastewater treatment plants are complex systems at the heart of which lies a complex set of concurrent physicochemical and biological processes (Bayo et al., 2006). The discharge of sewage into receiving waters without proper pre-treatment can generate serious problems to human health and the environment. Accordingly, the search for effective wastewater treatment strategies has attracted increasing attention in recent research. In fact, wastewaters can be treated and reused in a variety of purposes, particularly in countries facing water scarcity (Grant et al., 2012). In some extreme cases, such as the drought hitting Barcelona in 2008, wastewaters were treated and reused to increase drinking water resources (López-Serna et al., 2012).

Wastewater treatment processes can be divided into three broad categories, namely activated sludge, rotating biological contactor (RBC), and trickling filter. In fact, the activated sludge is the most common type of biological wastewater treatment process in the world (Cardot, 1999). Sewage treatment plant operators monitor periodical reports on a number of performance indicators. These include total suspended solids (TSS), chemical oxygen demand (COD) and 5-day biochemical oxygen demand (BOD_5), phosphorus and nitrogen. Other parameters, such as the stream flow rate and energy consumption, should be regularly examined. Indeed, the increasingly severe constraints on the quality of effluent discharges have induced parallel increases in energy consumption, which may account for about 30% of a plant's operation cost (Bourrier et al., 2010). The energy consumption of a wastewater treatment plant (WWTP) varies according to the wastewater or sludge treatment method, operation mode and installation size. Biological treatment alone may account between 60 and 80% of the total energy consumption.

Although several research works have investigated the characteristics and efficiency of WWTPs (Pons et al., 2004; Tas et al., 2009; Henze et al., 1997), only few studies were focused on the comparison between different WWTPs with different treatment processes

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and capacity (Hospido et al., 2008; Ravi Kumar et al., 2010).

The wastewater services in Tunisia have undergone considerable expansion and development, particularly with the creation of the National Sanitation Office (ONAS). The ONAS consists of a network of 110 plants distributed throughout the country. The region of Sfax (Tunisia) contains seven WWTPs that use different treatment processes. Several studies have been conducted on the WWTP of Southern Sfax before (Ouali et al., 2009) and after (Belhaj et al., 2014) rehabilitation in 2006. These authors have analyzed the physicochemical characteristics of this WWTP at different periods of time and used various types of multivariable analyses.

The present work aims to evaluate the performance and treatment efficiency of four WWTPs at various regions in Tunisia (Southern Sfax, Kerkennah, Hencha, and Agareb) over a period of four years (2011–2014) using the already-mentioned quality indicators. The multivariate analyses (Redundancy analysis (RDA) and one-way analysis of variance (one-way ANOVA)) were employed to compare three WWTPs, Kerkennah, Hencha and Agareb, which received the same influent (domestic wastewater) and used different wastewater treatment processes, namely activated sludge + RBC, activated sludge and trickling filter, respectively (Fig. 1). On the other hand, two WWTPs, Southern Sfax and Hencha, which used the same wastewater treatment process, activated sludge, but with different wastewater quality were compared.

In order to ameliorate the wastewater treatment, we developed an electrochemical process to enhance wastewater treatment at one of the WWTPs.

2. Materials and methods

2.1. Study site and sampling

The WWTP of Southern Sfax is located at 5.5 km in the South of the city of Sfax, Tunisia. It was built in 1983 and rehabilitated in 2006 (Belhaj et al., 2014). The treatment plant of Kerkennah is situated at 3 km away from Erramla (located in the island of Kerkennah, Sfax, Tunisia). The treatment plant of Hencha is located at 42 km in the North of the city of Sfax. The treatment plant of Agareb is 20 km west of Sfax.

The biological treatment in the Southern Sfax plant consists in alternating anoxic/aerobic bioreactors; air is supplied into the aerobic reactors with many surface aerators. The supply of O_2 in the aeration basin of Kerkennah and Hencha plants is provided by aeration compressor. The treatment process in Kerkennah plant is a combination of anaerobic pre-treatment with aerobic post-treatment, while the characteristic of the aeration basin of the Hencha plant is the alternation of aerobic/anoxic conditions (Fig. 1).

The design characteristics of the various treatment plants are shown in Table 1. The wastewater influent is almost domestic for Kerkennah, Hencha and Agareb plant but domestic joint to industrial wastewater in the WWTP of Southern Sfax. The sludge loading (SL) rates determined in biological treatment systems using activated sludge give an approximation of the relationship between the daily pollution flow to be eliminated and the implemented purifying bacterial mass (Degremont, 2002). Hydraulic Retention time (R_t) refers to the residence time of the wastewater at a basin, with R_t = volume of the activation basin/flow (Miller et al., 2010).

The study was carried out over a period of 4 years (2011–2014). Wastewater samples were collected at three sampling points within each of the treatment plants, namely the inlet (i), outlet (o) sites and activation basin. The samples were collected in polyethylene bottles for physicochemical analysis. Bacteriological samples were collected in sterile glass bottles. The samples were stored at 4 °C in the dark and immediately transported to the laboratory for characterization and analysis.

2.2. Physicochemical analyses, flow rates and energy

The physicochemical properties of the samples were analyzed according to AFNOR and ISO standard methods. The pH was analyzed using a pH meter (WTW 3000). The electrical conductivity (EC) and salinity (S) were measured by a multi-parameter conductimeter (WTW 3000). Chlorides are titrated with the silver nitrate solution (0.1 M) in the presence of a potassium chromate (1%) indicator solution (NF B56-017, 1980). Flow rates (FR) measurements were performed by flow meters installed at the outlet of the WWTPs. Energy (E) was measured by an energy meter (Tunisian company of electricity and gas: STEG). Data on rainfall were obtained from the ministry of agriculture and water resources (Tunisia).

2.3. Water quality indicators

The COD was determined with the reactor digestion using a HACH DR 2010 analyzer in accordance with standard procedures (NF T90-101, 2001). The BOD_5 was determined in mg/l by the manometric method using an Oxytop (BSB-controlled Model OxiTop WTW) in accordance with standard protocols (NF EN 1899-1, 1998). Energy efficiency (EE), which refers to the amount of electricity consumed according to the amount of BOD_5 removed, was calculated by the following formula: EE (KWh/kg BOD_5 removed) = daily amount of energy consumption (KWh = kilowatt hour)/daily reduction in BOD_5 load (kg). The TSS was measured in mg/l by filtration to 0.45 μm and drying at 110 °C (NF EN 872).

Moreover, the annual mean values of the total Kjeldahl nitrogen (TKN) were measured by Titrimetric determination after mineralization and distillation according to the Kjeldahl method (FN EN 25663, 1994). Ammonia nitrogen (NH_4^+), nitrate (NO_3^-) and total phosphorus (TP) annual contents were measured according to the AFNOR standards (NF T90-015-1, 2000; ISO 7890-3, 1989; ISO 6878, 2004). The removal efficiency (r) of the treatment plants was determined by the following formula $((C_i - C_0)/C_i)^*100$ (C_i is the concentration of any parameter in mg/l at the inlet of the plant and C_0 is the concentration at the outlet).

2.4. Bacteriological parameters, heavy metals and microscopic observation

The annual mean values of bacteriological tests were performed at the outlet sites. The enumeration of faecal coliforms (FC) and faecal streptococci (FS) was determined using the most probable number (MPN) technique in accordance with ISO 9308-2 (1990) and AFNOR standards (NF T90-411, 1989). FC counts were determined by Brilliant Green Bile Broth (BGBB) with Durham tube. The enumeration of FS was performed on a Rothe's medium and a Litsky's medium for presumptive test and confirmatory tests, respectively. For the detection of *Salmonella* and *Vibrio cholera* (ISO 6340, 1995; NT ISO 21872-1, 2007), samples were taken in June and September 2014 and were cultured on SS media (Biokar diagnostics agar) and TCBS (Thiosulfate-citrate-bile salts-sucrose agar) after enrichment in selenite-cystine broth and buffered peptone water, respectively.

The annual mean values of the heavy metals (Pb, Cu, Ni, Zn, Cr and Cd) were determined in accordance with NT ISO15587, 2007 and NT ISO 11855, 2009 and by a Perkin-Elmer model Analyst 300 flame atomic absorption spectrometer (Norwalk, CT, USA). Thus, all the values determined in this work were compared to the Tunisian standard values (sv) (NT.106.002, 1989). Samples collected in November 2014 from the activation basin of the WWTPs (using activated sludge process) were also directly observed under phase-contrast microscopy using an Olympus light microscope BX-50 (Canler et al., 2011).