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Reliability analysis of low-cost, full-scale domestic wastewater treatment plants for reuse in aquaculture and agriculture

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ABSTRACT

The current paper assesses the reliability coefficients of fifty six low-cost, full-scale wastewater treatment plants, including nine different treatment technologies for wastewater reuse in aquaculture and agriculture in northeast Brazil. This was carried out with the aim to evaluate alternatives for sustainable wastewater reuse in communities experiencing water scarcity. The technologies evaluated include septic tanks (ST); septic tanks + anaerobic filters (ST + AF); septic tanks + anaerobic filters + chlorination (ST + AF + Cl); facultative ponds (FP); facultative + maturation ponds (FP + MP); anaerobic + facultative + maturation ponds (AP + FP + MP); facultative aerated ponds + facultative + maturation ponds (FAP + FP + MP); upflow anaerobic sludge blanket reactors (UASB); and upflow anaerobic sludge blanket reactors + chlorination (UASB + Cl). The parameters used for the analysis include chemical oxygen demand, total suspended solids, *Escherichia coli* and biochemical oxygen demand. By applying an 80% reliability level for standard compliance, the study aimed at presenting relevant, realistic and achievable targets for the evaluated parameters. Discharge limits for agriculture and aquaculture were obtained from a compilation of international and Brazilian guidelines. Performance data showed, in some cases, great variability among wastewater treatment plants of the same type, highlighting the importance of good management and operation. The technologies that presented the highest reliability for wastewater reuse were AP + FP + MP systems (waste stabilization ponds), followed by ST + AF + Cl and FAP + FP + MP. UASB and UASB + Cl performed similarly to ST + AF systems whilst the worst performances were observed for ST, FP + MP and FP. Results have shown that low-cost, full scale wastewater treatment plants are able to provide a suitable effluent for wastewater reuse in agriculture and aquaculture when an 80% reliability standard is applied.

1. Introduction

It is estimated that over 50% of the world's population will suffer water shortages in the next 30 years (Postel, 1997; United Nations Environment Programme, 2002; Hunt, 2003). The areas which will be worst affected are those found in the developing world, thus affecting mostly countries with fragile and susceptible socio-economic conditions, presenting significant levels of poverty (Hinrichsen et al., 1998).

Currently, over half the world's rivers, lakes and coastal waters are heavily contaminated with untreated industrial, domestic and agricultural wastewater (United Nations Environment Programme, 2002), presenting high numbers of faecal bacteria (Ceballos et al., 2003) and imposing an unprecedented burden of excreta related-disease upon the poorest populations (Mara, 2003). Furthermore, the pressure exerted by agriculture – which consumes around 70% of the water available globally (FAO, 2009) – in conjunction with other industrial activities and high population growth in developing countries, calls for a more sustainable and ecological approach to the management of the global water abstraction. Wastewater is produced throughout the year and contains nutrients necessary for

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fish and plant growth. Treated wastewater is therefore a reliable water source for agriculture and aquaculture, especially in areas which present high levels of aridity and those prone to an increase in climate change induced droughts (Mara, 2003; Angelakis et al., 2003; Friedler, 2000).

Water quality standards for agriculture and aquaculture are usually set by international and local standards (WHO, 2006a,b; Dos Santos, 2006; Mota et al., 2007; Silva et al., 2001) in order to minimise health risks and environmental impacts. Furthermore, such limits can often be based on pertinent values required for the local area and communities, aiming to avoid the concept of 'overkill', as described by Mara (2003). This concept refers to exaggerated, overly conservative discharge standards sometimes adopted by developing countries following the example of industrialised ones (Johnstone and Horan, 1996). This leads to the implementation of overly expensive wastewater treatment plants requiring high capital and maintenance costs and, as a consequence, local communities being unable to pay the associated high charges. This in certain cases has led to municipalities and wastewater companies halting construction and operation of wastewater treatment plants, resulting in exposure to untreated water and leading to even higher health risks and environmental impacts. It is crucial to set discharge guidelines which take into consideration local and regional socio-economic, institutional, and climatic conditions (Blumenthal et al., 2000; Oliveira and von Sperling 2008a,b).

The current study is aimed at evaluating a wide range of low-cost, full-scale wastewater treatment technologies for reuse in agriculture and aquaculture using a more realistic and less onerous compliance standard of 80%. A 95% reliability level is frequently adopted for surface water effluents (Oliveira and von Sperling 2008a), which represents a requirement for more stringent effluent standards to be achieved when compared to those needed for irrigation and aquaculture.

Reliability refers to the percentage of time the expected effluent values meet the pre-set discharge limits (Dean and Forsythe, 1976a, b; Niku et al., 1979, 1981; Tanaka et al., 1998; Crites and Tchobanoglous, 2000; Metcalf and Eddy, 2002; Oliveira and von Sperling 2008a,b). For example, a WWTP will be 100% reliable if the effluent it produces never exceeds the discharge limits. Due to variations in raw wastewater characteristics and in actual wastewater treatment performance, the probability of failure to meet discharge standards should always be considered during design and policy making.

Therefore, a mean value should be applied which would ensure this failure is avoided within a certain reliability level. This can be calculated by means of the coefficient of reliability (also known as COR), which relates the mean effluent values of individual parameters to the standards that must be achieved, as described by Niku et al. (1979) and demonstrated in more detail by Oliveira and von Sperling (2008a,b).

However, reliability analyses of this kind have never been conducted as the primary methodology to evaluate the reuse of treated wastewater in aquaculture and agriculture. Alternative methodologies are based on risk assessments, probabilistic modelling, probability functions, and generalised linear models (WHO, 2006a,b; Benedetti et al., 2010; Vera et al., 2011; Weirich et al., 2011).

The current paper assesses the reliability coefficients of fifty six low-cost, full-scale wastewater treatment plants, including nine different treatment technologies for wastewater reuse in aquaculture and agriculture in northeast Brazil.

2. Methodology

2.1. Technologies evaluated

The data gathered for the analysis of reliability of wastewater treatment technologies was obtained directly from CAGECE, the water company operating for the state of Ceará in northeast Brazil (Fig. 1). The dataset was comprised of 12,275 values recorded from 56 wastewater treatment plants (WWTP) situated within and around the city of Fortaleza, including the 9 different wastewater treatment technologies described below. Values have been obtained from late 2005 until early 2009. During that time span, data for a few months were absent for certain parameters in different treatment plants as sampling and measurements were not carried out consistently. The technologies evaluated were:

- 5 septic tanks (ST);
- 17 septic tanks + anaerobic filters (ST + AF);
- 3 septic tanks + anaerobic filters + chlorination (ST + AF + Cl);

Fig. 1. Ceará, northeast Brazil – WWTPs regional location.