Ecological Engineering 82 (2015) 6–14

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

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

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ARTICLE INFO

Article history:
Received 31 July 2014
Received in revised form 20 March 2015
Accepted 10 April 2015
Available online 22 April 2015

Keywords:
Wastewater reuse
Wastewater treatment
Aquaculture
Irrigation
Reliability

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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http://dx.doi.org/10.1016/j.ecoleng.2015.04.081
0925-8574/

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.

- 8 facultative ponds (FP);
- 2 facultative ponds + maturation ponds (FP + MP);
- 6 anaerobic ponds + facultative ponds + maturation ponds (AP + FP + MP);
- 1 single aerated facultative pond + single facultative pond + single maturation pond (AFP + FP + MP);
- 3 upflow anaerobic sludge blanket (UASB) without post treatment;
- 11 upflow anaerobic sludge blanket + chlorination (UASB + Cl).

2.2. Discharge limits

Discharge limits for agriculture and aquaculture were obtained from a compilation of international and Brazilian sources (Dos Santos, 2006; WHO 2006a,b; Governo do Estado do Ceará, 2002; Mota et al., 2007; Silva et al., 2001). COD and BOD, effluent release to surface waters standards were adopted as the upper parameter limits, as no other parameter limits were found to be pertinent.

The discharge limits determined as suitable for reuse in agriculture and aquaculture (in line with biological requirements needed by crops and fish to thrive) on the context of this study and appropriate for developing countries in general are shown below:

- Chemical oxygen demand (COD): 200 mg/L (Governo do estado do Ceará, 2002)
- Biochemical oxygen demand (BOD): 60 mg/L (Dos Santos et al., 2007; Mota et al., 2007)
- *Escherichia coli* for unrestricted irrigation: 10^3 for every 100 mL (Dos Santos, 2006; Dos Santos et al., 2007; WHO, 2006a)
- *E. coli* for restricted irrigation and aquaculture: 10^4 MPN for every 100 mL (Dos Santos, 2006; Dos Santos et al., 2007; WHO, 2006a,b)
- Total suspended solids (TSS): 60 mg/L (Oliveira and von Sperling, 2008a)

The diverse effluent parameter values obtained showed great variability in their sampling frequency and monitoring periods for each wastewater treatment technology. Some important parameters such as free residual chlorine, total nitrogen, ammoniac nitrogen and total phosphorous had to be excluded from the analysis due to poor data availability from full-scale plants. Heavy metal contaminants have also been excluded as the WWTP evaluated received primarily domestic wastewater, which usually do not contain substantial amounts of heavy metals, as opposed to some industrial wastewaters.

2.3. Reliability analysis

2.3.1. Coefficient of reliability (COR)

The reliability of WWTPs can be calculated by using a coefficient of reliability (COR) as developed by Niku et al., (1979) based on assumed log-normality of the data. This has been confirmed for the data used in this study, as log-normality was shown to be the best fit for the referred parameters (Kolmogorov, Chi-squared and Anderson tests were applied). Log-normality has frequently been reported as the most representative fit for the parameters being analyzed as shown by Dean and Forsythe (1976a,b); Niku et al. (1979, 1981); Niku and Schroeder (1981); Charles et al. (2005); Oliveira (2006) and Oliveira and von Sperling (2008a,b).

Coefficients of variation (CV) of the WWTP technologies analysed in this study were calculated for the parameter measurements available. The COR relates mean design or operation concentrations of each parameter being analysed to the standards required based on probability:

$$m_x = (\mathrm{COR})X_s, \tag{1}$$

where m_x is the mean design or operation effluent concentration (units according to parameter type), X_s the effluent concentrations parameter standard or limit (its units according to the parameter type) and COR represents the coefficient of reliability.

The coefficient of reliability COR can be calculated from the following equation:

$$\mathrm{COR} = \sqrt{\mathrm{CV}^2 + 1} \times \exp\left\{-Z_{1-\alpha}\sqrt{\ln\left(\mathrm{CV}^2 + 1\right)}\right\}, \tag{2}$$

where CV is the coefficient of variation (standard deviation divided by the mean actual effluent value), α represents the probability of meeting the discharge standards and $Z_{1-\alpha}$represents the standardized normal variate as represented in the values of standardized normal distributions table (Oliveira and von Sperling 2008a,b) (Table 1).

It should be noted that COR values have been obtained based on the values provided by the original data and not from the logarithm of the data (Oliveira and von Sperling 2008a,b). Once the COR values were obtained, the design/operational values that would result in an optimum performance, reaching the required discharge standards/limits, were calculated by means of Eq. (1) for all of the wastewater treatment technologies.

2.3.2. Expected compliance with adopted discharge standards

Once the CV values were obtained, an expected percentage of compliance with the set limits could be calculated using the actual effluent values for each wastewater treatment technology and their parameters.

Expected compliance percentages were calculated by applying Eq. (3) described by Niku et al. (1979), which takes into consideration the relationship between normal and log-normal distributions, and some algebraic manipulations that take into account the CV values.

$$Z_{1-\alpha} = \frac{\ln X_s - \left[\ln m'_x - \frac{1}{2}\ln\left(\mathrm{CV}^2 + 1\right)\right]}{\sqrt{\ln\left(\mathrm{CV}^2 + 1\right)}} \tag{3}$$

where m'_x is the actual mean effluent value for the analysed parameter.

Once $(1 - \alpha)$. values have been calculated, a value belonging to the cumulative probability of the standardized normal distribution (distribution Z) can be obtained. This was carried out applying the means of the NORMSDIST function in Microsoft Excel, which can also be found in other statistical sources as shown by Snedecor and Cochran (1989) and Montgomery and Runger (1999).

2.3.3. Mean ideal design concentration (MIDC)

The effluent values required for the parameter limits to be met can be calculated using Eq. (1) for each wastewater treatment technology, by applying their mean CV value and $\alpha = 20$. This has been calculated to easily compare the mean ideal design

Table 1
Mean parameter concentrations of 9 wastewater treatment technologies.

Cumulative probability $(1 - \alpha)$ = reliability	$Z_{1-\alpha}$
50	0.000
60	0.253
70	0.525
80	0.842
90	1.282
95	1.645
98	2.054
99	2.326

Table 2
Mean parameter concentrations of 9 wastewater treatment technologies.

Parameters		Technologies								
		ST	ST + AF	ST + AF + Cl	FP	FP + MP	AP + FP + MP	FAP + FP + MP	UASB	UASB + Cl
COD	Raw influent (mg/L)	974	996	538	709	701	803	571	721	803
	Treated effluent (mg/L)	646	656	299	284	209	137	188	266	364
E. coli (NMP/100 ml)[a]	Raw influent (MPN/100 mL)	2.E + 07	4.E + 07	2.E + 07	5.E + 07	7.E + 07	2.E + 07	3.E + 07	8.E + 07	1.E + 07
	Treated effluent (MPN/100 mL)L)	8.E + 02	3.E + 02	4.E + 02	8.E + 04	4.E + 03	9.E + 01	5.E + 02	7.E + 02	4.E + 02
TSS (mg/L)	Raw influent (mg/L)	372	717	191	280	268	354	178	391	316
	Treated effluent (mg/L)	295	323	66	149	93	61	94	131	148
BOD (mg/L)	Treated effluent (mg/L)	–	–	–	109	–	50	–	–	–

[a]Geometric mean for coliforms.

Table 3
CV and COR values from the 9 WWTP technologies at an 80% reliability level.[a]

Technologies	Coefficient of variation (CV)				Coefficient of reliability (COR)			
	COD	BOD	TSS	*E. coli*	COD	BOD	TSS	*E. coli*
ST	1.06	–	1.15	2.72	1.06	–	0.76	0.99
ST + AF	2.74	–	5.52	6.44	1.15	–	1.14	1.90
ST + AF + Cl	2.01	–	2.21	9.61	1.30	–	0.91	2.11
FP	0.77	0.63	0.48	3.34	0.88	0.75	0.79	0.97
FP + MP	1.01	–	0.78	0.31	1.34	–	0.77	1.31
AP + FP + MP	0.71	0.22	0.84	0.70	0.88	1.02	0.78	0.84
AFP + FP + MP	0.48	–	0.48	0.67	1.15	–	0.78	0.75
UASB	0.51	–	1.54	2.19	0.97	–	0.80	1.16
UASB + Cl	0.83	–	1.05	6.60	0.79	–	0.76	1.56

[a]Refers to both; unrestricted and restricted irrigation.

concentration (MIDC) and the actual mean concentration (AMC) obtained for each parameter and each WWTP type.

3. Results and discussion

The mean influent and effluent concentrations per parameter of the 9 WWTP technologies are shown in Table 2.

3.1. Coefficient of variation (CV) and coefficient of reliability (COR) values

The mean CV values and COR values of the 9 wastewater treatment technologies for each parameter are shown in Table 3 and as box whisker plots (Figs. 2–5), presenting all the values of the WWTPs from each treatment technology.

Table 3 shows that there are great differences for mean CV and COR values in each parameter when the different wastewater treatment technologies are compared. The differences are even more extreme when box whisker plots are analysed (Figs. 2–5),

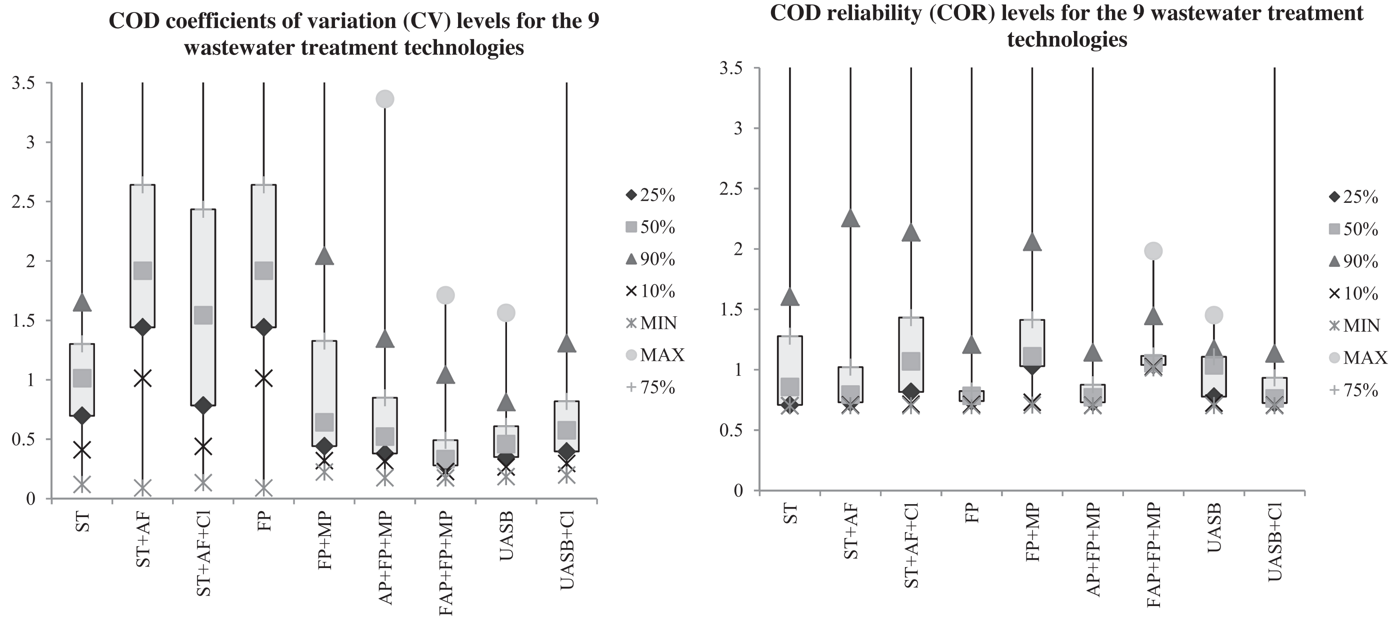

Fig. 2. COD coefficients of variation (CV) and coefficients of reliability (COR) values for the 9 wastewater treatment technologies.

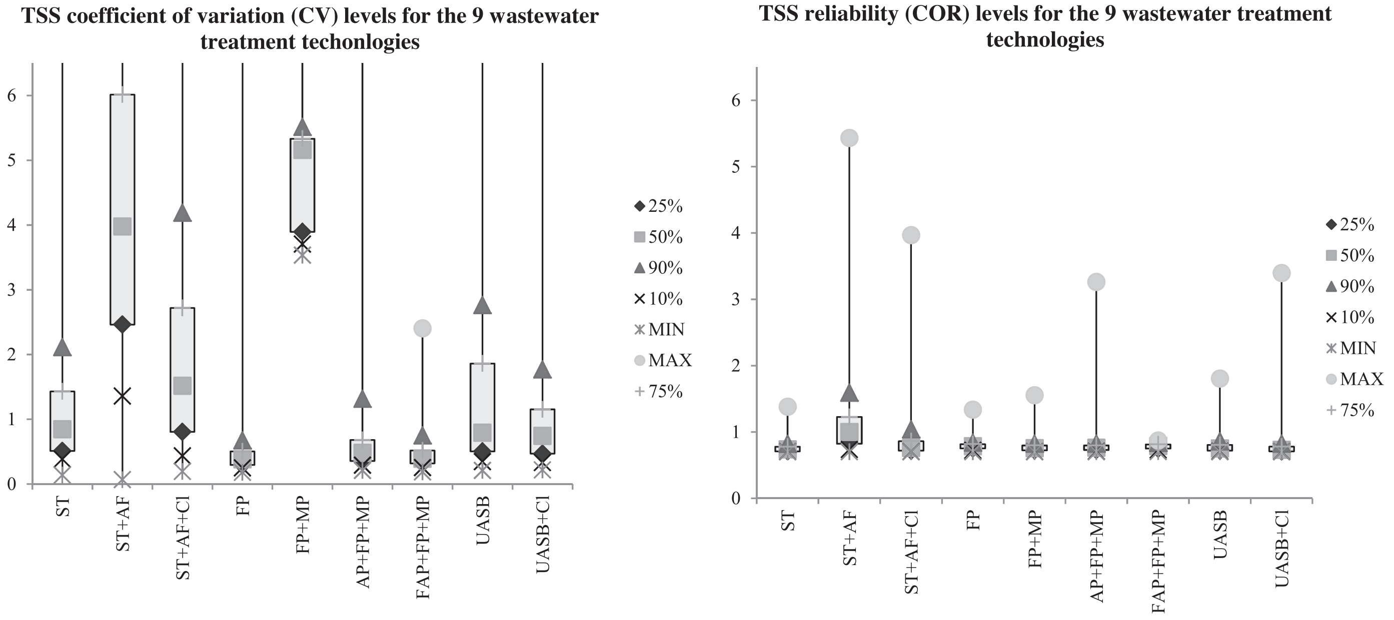

Fig. 3. TSS coefficients of variation (CV) and coefficients of reliability (COR) values for the 9 wastewater treatment technologies.

illustrating great ranges from the maximum and minimum values. Most mean CV values do not fall below 1.0, as would be expected, according to Oliveira and von Sperling (2008a). This difference is mainly due to the fact that there is great variance and unevenness in the effluent values. On a general basis, such is the case in most anaerobic treatment technologies when compared to aerobic systems. These high mean CV values are thus representative of unstable operational levels by these technologies which could be caused by a lack of maintenance, influent disturbances (Oliveira and von Sperling, 2006, 2008a) or erroneous parameter readings. The most stable operational values according to the CV values are observed for FAP + FP + MP (as its only 1 WWTP) and the AP + FP + MP systems (6 WWTPs with different numbers of facultative and maturation ponds), followed by the other pond systems (FP and FP + MP); then by the UASB + Cl and UASB systems; and finally by ST systems.

Increasing CV values showed little correlation with decreasing COR values. This is thought to be due to the extreme variations between the CV values and the surpassing of COR values above 1.0 obtained in this study. These higher COR values are attributed to the lower effluent values in this study and due to the reliability level applied (80%). Furthermore, many of the effluent values as

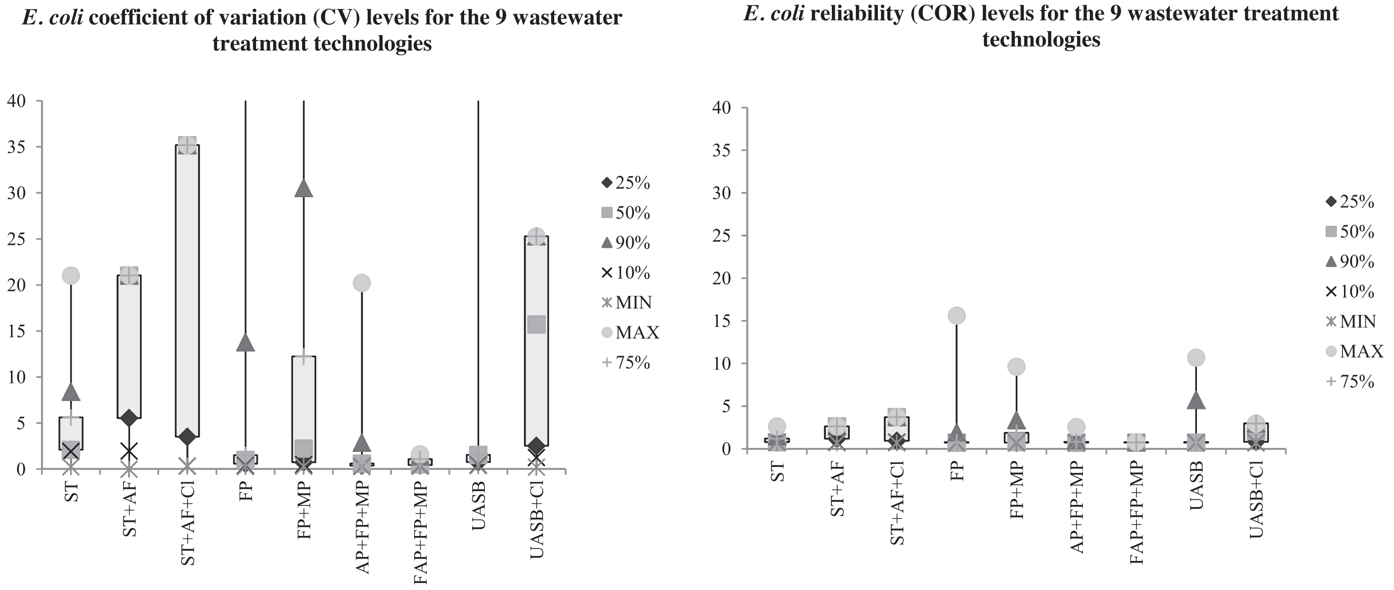

Fig. 4. *E. coli* coefficients of variation (CV) and coefficients of reliability (COR) values for the 9 wastewater treatment technologies.

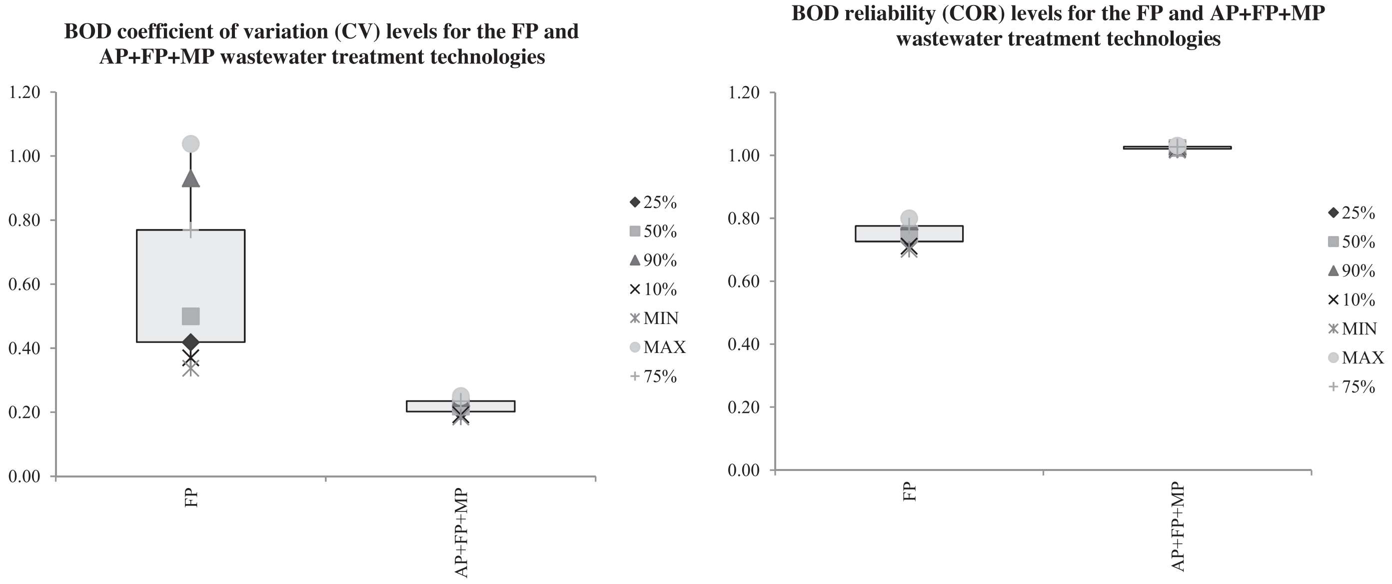

Fig. 5. BOD coefficients of variation (CV) and coefficients of reliability (COR) values for the FP and AP + FP + MP wastewater treatment technologies.

Table 4
Mean ideal design effluent concentrations required to achieve 80% compliance with the standards against the actual effluent levels being produced.

Technology	COD (mg/L)		BOD (mg/L)		TSS (mg/L)		*E. coli* – aquaculture and restricted irrigation (MPN/100 mL)		*E. coli* – unrestricted irrigation (MPN/100 mL)	
	MIDC	AMC	MIDC	AMC	MIDC	AMC	MIDC	AMC	MIDC	AMC
ST	211	646	–	–	46	295	9.86E + 03	7.74E + 02	9.86E + 02	7.74E + 02
ST + AF	231	656	–	–	69	323	1.90E + 04	3.27E + 02	1.90E + 03	3.27E + 02
ST + AF + Cl	260	299	–	–	55	66	2.11E + 04	3.66E + 02	2.11E + 03	3.66E + 02
FP	176	284	45	109	47	149	9.74E + 03	7.74E + 04	9.74E + 02	7.74E + 04
FP + MP	268	209	–	–	46	93	1.31E + 04	4.00E + 03	1.31E + 03	4.00E + 03
AP + FP + MP	177	137	61	50	47	61	8.39E + 03	8.63E + 01	8.39E + 02	8.63E + 01
AFP + FP + MP	229	188	–	–	47	94	7.50E + 03	4.89E + 02	7.50E + 02	4.89E + 02
UASB	194	266	–	–	48	131	1.16E + 04	7.09E + 02	1.16E + 03	7.09E + 02
UASB + Cl	179	364	–	–	46	148	1.56E + 04	3.83E + 02	1.56E + 03	3.83E + 02

Discharge standards: COD = 200 mg/L; TSS = 50 mg/L; *E. coli* – aquaculture and restricted irrigation = 10000 MPN/100 mL; *E. coli* – unrestricted irrigation = 1000 MPN/100 mL.
MIDC: mean ideal design concentrations; AMC: actual mean concentrations.

shown in the reliability analysis were found to be well below the required parameter limits, and thus explaining some of the very high COR values. This means that the lower the effluent value, the higher the COR, when the effluent value is lower than that of the parameter limit – suggesting that even higher levels of reliability (higher than 80%) could be applied for these parameters if necessary (Oliveira and von Sperling 2008a).

Low COR values represent the need for lower treated effluent concentrations and thus the need to improve operational methods or maintenance of the WWTPs. COR values in this study did not fall below 0.75, thus suggesting that it will be easier for these treatment technologies to produce the required effluent values – these are obtained by multiplying the COR values by discharge limits as described below.

The effluent values required for compliance were calculated for each wastewater treatment technology. These have been presented in Table 4 as the mean ideal design concentration (MIDC) and have been listed next to the actual mean concentration (AMC) obtained for each parameter and each WWTP type.

From the results, it is clear that in most cases the actual effluent levels exceed those required to obtain the desired reliability, especially for COD in anaerobic systems and TSS for aerobic systems. In contrast, levels required for *E. coli* were higher than those being produced by most wastewater treatment technologies, except for FP.

Table 5
Mean percentage of compliance with the discharge standard at 80% reliability level.

Technology	COD	BOD	TSS	*E. coli* – aquaculture and restricted irrigation	*E. coli* – unrestricted irrigation
ST	27	–	20	98	73
ST + AF	45	–	51	92	86
ST + AF + Cl	58	–	66	93	75
FP	39	29	12	24	22
FP + MP	56	–	36	63	42
AP + FP + MP	77	79	54	100	100
AFP + FP + MP	56	–	28	100	84
UASB	40	–	38	93	52
UASB + Cl	32	–	30	96	78

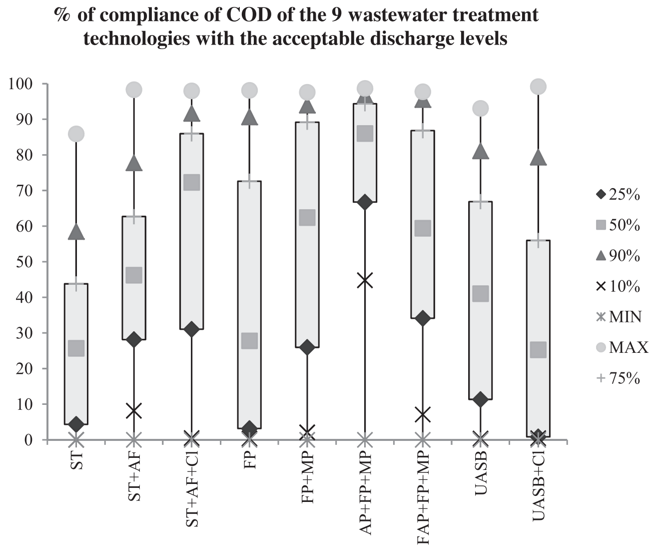

Fig. 6. COD percentage of compliance with the discharge standards at 80% reliability level.

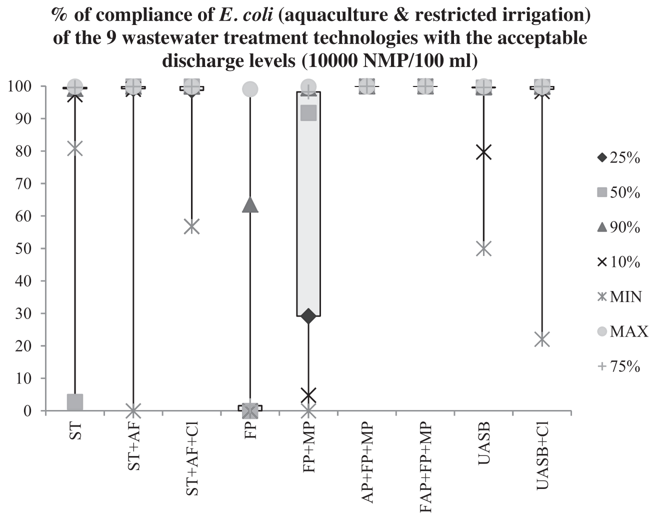

Fig. 8. *E. coli* for aquaculture and restricted irrigation percentage of compliance with the discharge standards at 80% reliability level.

AP + FP + MP systems provided most of their actual mean effluent values below those considered to be the ideal effluent values to achieve the 80% reliability. The superiority of this waste stabilization pond (WSP) system was clear, and more stringent reliability standards could be set for this system for *E.coli* and for all the other effluent standards, except TSS as suggested in research carried out by Oliveira and von Sperling (2008a).

3.2. Percentage of compliance using 80% reliability

The percentage of compliance has been calculated for each evaluated technology taking into consideration the 80% reliability level. The performance of each wastewater treatment technology is shown in more detail in Table 5 (showing mean percentage of compliance at 80% reliability) and in Figs. 6–10. It should be noted that the results are representative of the WWTPs performance if they were to maintain their operational levels.

The great fluctuations among individual values as seen in the previous results are also represented in these box-and-whisker plots (Figs. 6–10), and indicate the superiority of AP + FP + MP systems over other systems evaluated. The highest compliance values were obtained by this AP + FP + MP systems (Table 5), especially in its compliance with COD limits; presenting a mean compliance level of 77%, and having 75% of its values above 66.75%. Septic tanks, on the other hand, presented the lowest mean compliance standards for the same parameter (27%) with 75% of its values below 43.8% compliance.

ST + AF + Cl were the best of the anaerobic systems, showing superior removal of COD. For TSS, the best performances were also observed for the anaerobic technologies ST + AF + Cl and ST + AF

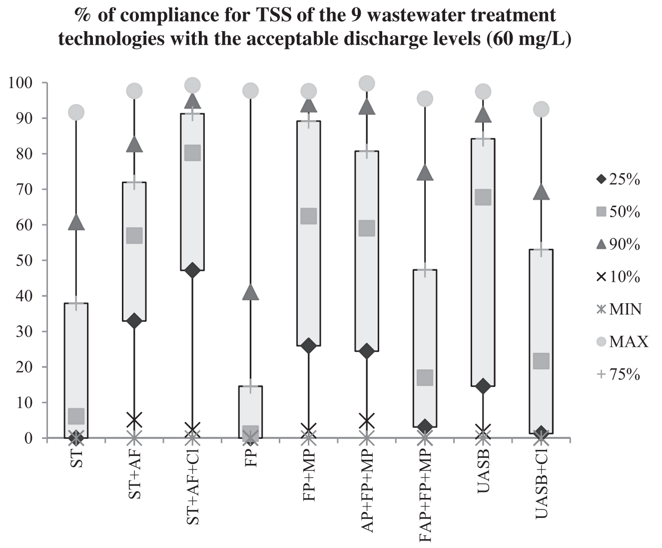

Fig. 7. TSS percentage of compliance with the discharge standards at 80% reliability level.

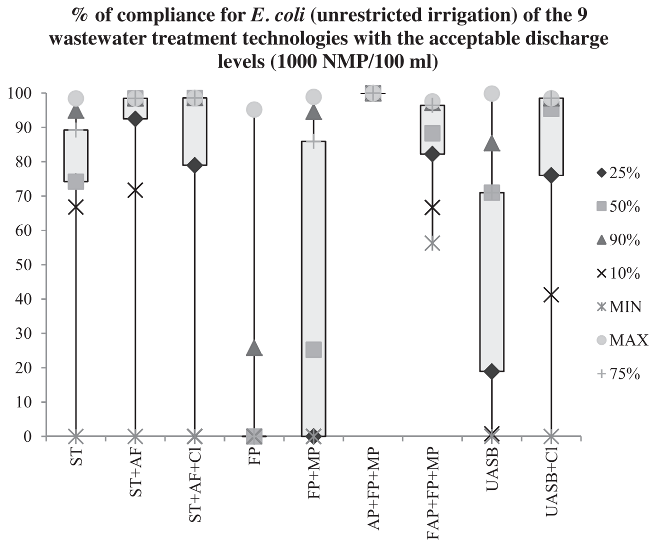

Fig. 9. *E. coli* for unrestricted irrigation percentage of compliance with the discharge standards at 80% reliability level.

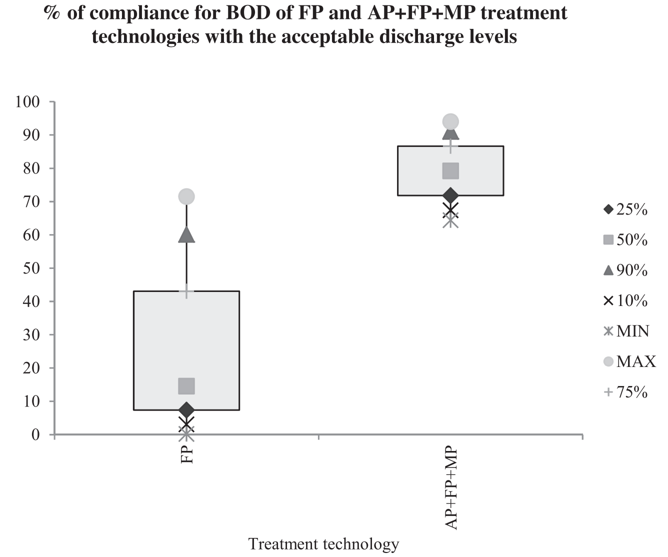

Fig. 10. BOD percentage of compliance with the discharge standards at 80% reliability level for FP and AP + FP + MP treatment technologies.

(corroborating observations by Von Sperling and Oliveira, 2009), followed by the AP + FP + MPs.

Fig. 11 shows the differences in performances of the wastewater treatment technologies evaluated. AP + FP + MP systems provided the best compliance. Further to this, if efficiency is calculated using the values from Table 2 it is clear that this technology also presents the best overall removal efficiencies (77% for COD, 79% for BOD and 100% for *E. coli* for aquaculture/restricted irrigation and for unrestricted irrigation (Table 2).

It is important to note that this study has focused in comparing treatment technologies, composed of varying number of WWTPs, which in some cases differ in design especially for the AP + FP + MP systems. Furthermore, they will also have undergone different maintenance standards, differing in frequency and quality, resulting in large differences between maximum and minimum values (as well as high CV values). There is also a considerable difference in the number of WWTPs included in the analysis per treatment technology, which can make the results biased depending on the number of measurements for individual parameters and their validity. This is represented for *E. coli* values for example, where ST (presenting only 2 measurements in 1 WWTP) provided better results than technologies considered to be superior, such as FP + MP (presenting various measurements for 2 WWTP's for this parameter).

4. Conclusion

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 – with the AP + FP + MP (WSP system) presenting the highest levels of compliance.

The reliability analyses showed to be a simple and straightforward methodology that can be used by sanitation companies to select appropriate wastewater treatment processes for reuse purposes.

The 80% reliability used represents a more pertinent target for water-scarce communities in developing regions which may be affected further by the impacts of climate change, and which use these low cost full-scale domestic wastewater treatment technologies. In such context, most treatment systems can be successfully used for wastewater reuse in agriculture and aquaculture at high compliance rates. Moves to implement such re-uses of wastewater should be implemented where identified to be feasible and relevant.

However, it is important to note that the current study focused only on the evaluation of treatment performances of various low-cost, sustainable, ecological technologies, and did not concentrate on assessing the potential health impacts which could result from using such technologies at lower reliability levels. Ideally, cost-effective public health policy on wastewater reuse should be based on the use of empirical epidemiological studies supplemented by microbiological studies of the transmission of pathogens in conjunction with model-based quantitative risk assessment for selected pathogens.

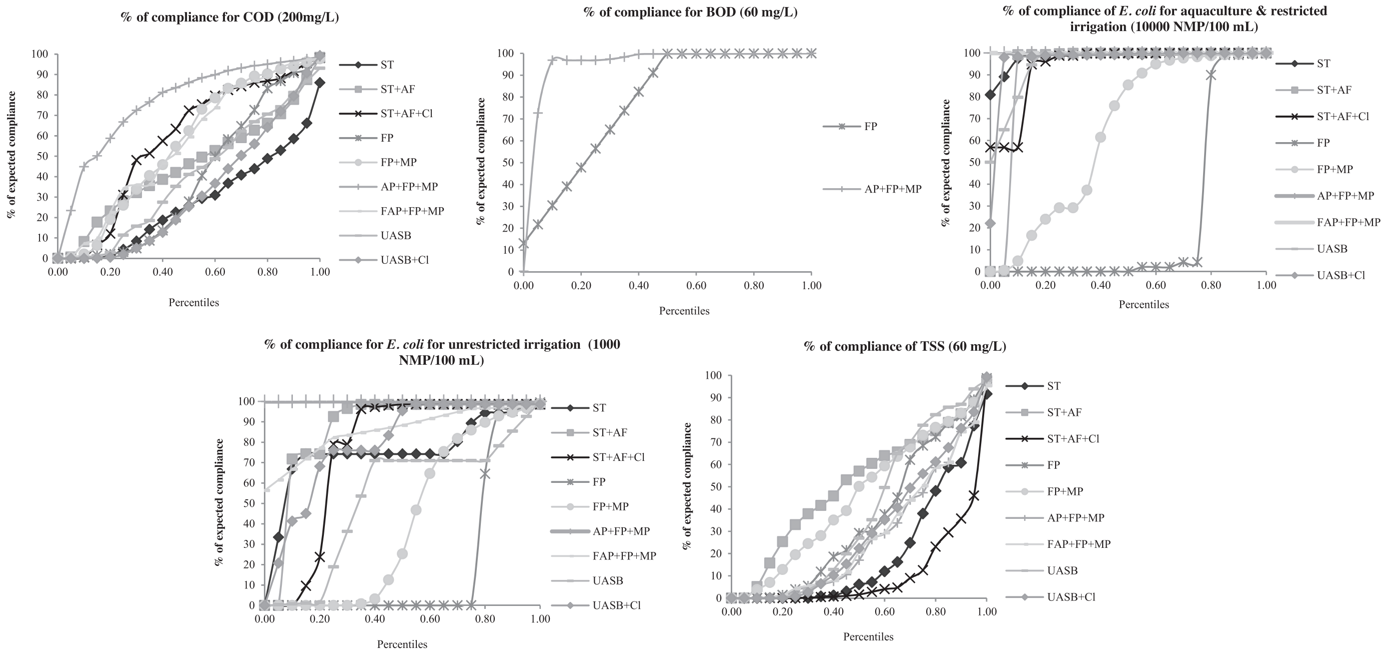

Fig. 11. Percentile values for the expected compliance with standards for all parameters, at an 80% reliability level.

Acknowledgements

This work was financially supported by the Royal Society (grant reference number JP090804), Engineers without Borders UK and by the School of Civil Engineering and Geosciences at Newcastle University. The authors would like to thank CAGECE for providing the raw data.

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Glossary

AF: Anaerobic filters

AMC: Actual mean concentration

AP: Anaerobic pond

BOD: Biochemical oxygen demand

CAGECE: Companhia de Água e Esgoto do Ceará

Cl: Chlorination

COD: Chemical oxygen demand

COR: Coefficient of reliability

CV: Coefficient of variation

E. coli: *Escherichia coli*

FAO: Food and Agriculture Organization

FAP: Facultative aerated pond

FP: Facultative pond

mg/l: Milligrams per litre

MIDC: Mean ideal design concentrations

MP: Maturation pond

MPN: Most probable number

ST: Septic tank

TSS: Total suspended solids

UASB: Upflow anaerobic sludge blanket

UN: United Nations

WHO: World Health Organization

WSP: Waste stabilization ponds

WWTP: Waste water treatment plant