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Elements for setting up discharge standards in developing countries based on actual wastewater treatment plant performance

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ABSTRACT

The paper analyses the capability of 166 full-scale wastewater treatment plants operating in Brazil, in order to achieve different quality targets for wastewater discharge. These targets cover a wide range of possible situations, reflecting usual practices adopted worldwide. Six different treatment processes have been investigated: septic tank + anaerobic filter, facultative pond, anaerobic pond + facultative pond, activated sludge, UASB reactors alone, UASB reactors followed by post-treatment. The parameters investigated were: BOD, COD, suspended solids, total nitrogen, total phosphorus and thermotolerant coliforms. Most technologies showed a poor performance, and some of them were not capable to achieve even relaxed standards. The paper presents elements for setting up discharge standards in developing countries, based either on values that may be achieved by treatment processes commonly applied or on best available technologies.

Key words | developing countries, effluent quality, performance evaluation, treatment systems

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INTRODUCTION

Several studies have shown that pollution levels tend to rise with increasing development, until development generates enough wealth to promote significant pollution control (Johnstone & Horan 1994, 1996; Seager 1994; Johnstone & Norton 2000; Von Sperling & Chernicharo 2002; Ragas *et al.* 2005).

Most developed nations have implemented long term standards that lead to an aquatic environment free from gross pollution, with low health risks. In general, this has taken many years and the recovery of the deteriorated aquatic ecosystem has not been easy nor has it been cheap. Johnstone & Norton (2000) report that the quality improvement has been based on the application of good engineering supported by the passing and enforcement of necessary legislation and the development of suitable institutional capacity to finance, design, construct, maintain and operate the required sewerage and sewage treatment systems.

However, many of the developing nations still have grossly polluted rivers and watercourses, being unable to reverse the unacceptable environmental degradation, which pose substantial risks to health. In general, improvements have been hindered by the lack of resources and finance, poor legislation, lack of appropriate institutional capacity for regulation and control, and, often, the lack of political will.

One way of controlling water pollution is by defining, applying and enforcing effluent standards for wastewater discharges. Standards from the developed world, including some unjustifiably very stringent standards, are frequently copied by developing nations, often leading to the use of inappropriate technology in pursuit of unattainable or unaffordable objectives. It is therefore important to adopt an approach that is appropriate in terms of protection of water quality, based on the specific economical, institutional, technological and climatic conditions of the country.

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Several publications (Dean & Forsythe 1976*a*,*b*; Niku *et al.* 1981; Berthouex & Hunter 1983; Vaughan & Russel 1983; Smith *et al.* 2001; Von Sperling & Chernicharo 2000, 2002) have investigated the performance of treatment processes in terms of effluent quality and compliance with discharge standards. These studies are important elements to the regulatory agencies for an appropriate definition of the effluent discharge and water quality standards. In most of the developing countries, the knowledge about the performance of the wastewater treatment technologies in operation is relatively scarce, with little structured consolidations in terms of overall extensive evaluations.

In this context, the objective of this paper is to extend the discussion undertaken by Von Sperling & Chernicharo (2002) about the capability of urban wastewater treatment technologies in achieving different levels of effluent quality. The effluent quality levels reflect a wide range of possibilities, allowing the interpretation for different scenarios and realities. Based on this analysis, elements for setting up discharge standards based on actual performance are given. The principle is that there is no sense in specifying discharge standards that are not compatible with existing wastewater treatment processes.

In this work, 166 full-scale wastewater treatment plants (WWTP) in operation in Brazil were evaluated in order to match compliance with various quality targets for wastewater discharges. These hypothetical quality targets were based on possible discharge standards that may be adopted on a worldwide basis, covering ranges that encompass stringent and relaxed limiting values.

Six technologies, comprising single and combined anaerobic and aerobic processes, located in Southeast Brazil (latitudes 20 to 22° South), in the states of São Paulo and Minas Gerais, were evaluated. Due to the large regional, climatic, social and economic diversity of the region investigated, the results obtained are likely to be representative for other Brazilian states and also for many other developing countries.

The treatment technologies selected for the study were: (i) septic tank + anaerobic filter (ST + AF), (ii) facultative pond (FP), (iii) anaerobic pond followed by facultative pond (AP + FP), (iv) activated sludge (AS), (vi) UASB reactor without post-treatment (UASB) and (vi) UASB reactor followed by several post-treatments (UASB + POST). All treatment plants receive wastewater from urban origin, mostly from domestic sources, but also incorporating occasional minor components of industrial effluents.

The parameters investigated were: biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), total nitrogen (TN), total phosphorus (TP) and faecal (thermotolerant) coliforms (FC).

METHODS

The data evaluated in this work were obtained directly from the operational records of the Water and Sanitation companies responsible for the operation of the treatment plants, located in Southeast Brazil. In total, almost 42,000 data from the 166 WWTP were analysed.

The hypothetical targets for the constituents BOD, COD, TSS, TN, TP and FC considered a wide range of possible discharge standards that may be applicable on a worldwide basis, depending on the level of stringiness or relaxation chosen by the environmental agency. Some of the values are applied by some environmental agencies in Brazil, whereas other values can be found in discharge standards from different countries. Table 1 shows the effluent concentrations and removal efficiencies adopted in this study. All individual data available from the WWTP were examined to evaluate their capability of achieving these different hypothetical discharge targets.

RESULTS AND DISCUSSION

Table 2 shows the number of units evaluated in each treatment technology, the mean influent flow, the mean concentrations of raw and treated wastewater and the mean removal efficiencies, taking into consideration the monitoring of BOD, COD, TSS, TN, TP and FC effluent concentrations. The monitoring period in which the data from the different treatment plants have been collected ranged from 1995 to 2003. Sampling frequency, monitoring period and measured parameters varied substantially from plant to plant, suggesting the existence of a wide variability in operational control level.

In general, a great variability was noticed in the effluent concentrations and in the removal efficiencies, considering

Table 1 | Hypothetical discharge targets adopted in the study

Targets	Constituents BOD_5 (mg/L)	COD (mg/L)	SS (mg/L)	TN (mg/L)	TP (mg/L)	FC (MPN/100 mL)
Effluent concentration	20	50	20	10	1	10^2
	40	100	40	15	2	10^3
	60	150	60	20	3	10^4
	80	200	80	25	4	10^5
	100	250	100	30	5	10^6
Removal efficiency	(%)	(%)	(%)	(%)	(%)	(log units removed)
	60	55	60	20	20	1
	70	65	70	40	40	2
	80	75	80	60	60	3
	90	85	90	80	80	4
						5
						6

Table 2 | Mean concentrations and mean removal efficiencies, according to the six treatment technologies

Constituent			ST + AF	FP	AP + FP	AS*	UASB reactor	UASB + POST†
Number of WWTP evaluated			19	73	43	13	10	8
Average flow (m^3/d)			205	400	1,628	64,484	3,038	253
BOD	Influent (raw)	(mg/L)	665	553	510	315	371	362
	Effluent (treated)	(mg/L)	292	136	89	35	98	42
	Removal efficiency	(%)	59	75	82	85	72	88
COD	Influent (raw)	(mg/L)	1,398	1,187	1,095	575	715	713
	Effluent (treated)	(mg/L)	730	525	309	92	251	141
	Removal efficiency	(%)	51	55	71	81	59	77
TSS	Influent (raw)	(mg/L)	479	430	411	252	289	334
	Effluent (treated)	(mg/L)	165	216	153	57	85	51
	Removal efficiency	(%)	66	48	62	76	67	82
TN‡	Influent (raw)	(mg/L)	78	69	78	47	43	
	Effluent (treated)	(mg/L)	61	38	45	22	48	
	Removal efficiency	(%)	24	44	39	50	−13	
TP	Influent (raw)	(mg/L)	9	9	11	3	7	7
	Effluent (treated)	(mg/L)	7	4	7	1	6	5
	Removal efficiency	(%)	15	46	37	46	−1.0	23
FC§	Influent (raw)	MPN/100 mL	2.9×10^7	5.3×10^7	2.0×10^8	3.7×10^7	1.2×10^8	1.8×10^8
	Effluent (treated)	MPN/100 mL	5.5×10^6	1.2×10^6	4.3×10^5	1.3×10^5	3.4×10^7	9.7×10^6
	Removal efficiency	Log Unit	1.0	1.6	2.2	2.0	0.6	2.8

*Activated sludge process includes: conventional and extended aeration.
†UASB + POST includes as post-treatment: aerated filter; anaerobic filter; trickling filter; flotation unit; facultative pond and maturation pond.
‡TKN (Total Kjeldahl Nitrogen) and TN were used.
§Geometric mean used for coliforms.

all the analyzed constituents and all treatment technologies. Amongst the various influencing factors, influent concentrations were observed to vary widely. The simpler treatment systems, that is, ST + AF, FP and AP + FP, showed systematically much higher influent and effluent concentrations for all constituents, except faecal (thermotolerant) coliforms. All treatment plants receive wastewater from urban origin, mostly from domestic sources, but also incorporating occasional minor components of industrial effluents. Separate sewerage systems are adopted in the systems investigated, but cross-connections occur at different degrees, meaning that a fraction of storm water may be present in the influent to the treatment plants during storm events. Possible explanations that could justify the high concentrations of raw wastewater treated by these processes could be: unreported industrial contributions, type of sampling practiced (prevalence of grab samples, collected at peak hours), low per capita water consumption, low infiltration rates, and low wastewater/water return coefficients (a fraction of greywater from many dwellings is not discharged in the sewage collection system), as discussed in more detail by Oliveira & von Sperling (2006).

As discussed in the Methods section, all individual data available from the 166 WWTP were examined to evaluate their capability of achieving the hypothetical discharge targets. The final results of the technologies considered the mean of the individual compliances obtained for the treatment plants. Figure 1, in the form of box-whisker plots, shows the maximum and minimum values, the 25 and 75% percentiles and the median of the BOD effluent concentrations and removal efficiencies obtained. The results concerning the other constituents are not presented graphically, but are incorporated in the final analysis.

In general, the plants presented a great variability in the percentages of compliance with all standards. In terms of BOD standards, most of the investigated WWTP were capable of achieving high percentages of compliance with the BOD limit concentrations of 100 and 80 mg/L. Even though the limit of concentration for BOD = 60 mg/L (discharge standard specified by most Brazilian states) is not particularly stringent compared with prevailing standards in developed countries, some of the technologies (notably ST + AF) demonstrated a median percentage of compliance close to zero per cent. As expected, the situation was worse considering more stringent standards (target: BOD ≤ 40 mg/L). Most plants could not achieve these standards and only activated sludge system had a median percentage of compliance higher than 50 per cent, considering the compliance with the BOD standard of 20 mg/L.

The levels of compliance in terms of the removal efficiency of BOD were relatively high when the required removal efficiencies were low (targets: 60 and 70% removal efficiency). However, some plants presented very poor results, especially one septic tank + anaerobic filter (ST + AF) that presented no compliance at all with the target of 60%. For the upper level of removal efficiencies, such as 80 and 90%, only the AS and UASB reactor followed by post treatment achieved high levels of compliance.

The percentages of compliance with COD, TSS, TN, TP and FC targets were computed and, in general, the best comparative performance was obtained by activated sludge (AS) and UASB reactor followed by post-treatments (UASB + POST). It is worth mentioning that the observed low removal efficiencies in terms of nutrients were expected, since the wastewater treatment processes were not designed to remove TN or TP.

All results were summarized and evaluated to verify the best performance obtained by individual plants. The WWTP that presented the best results were adopted as a benchmark, indicating that their performance could be considered to be achievable. In order to choose the best performance a criterion was adopted, which consisted in selecting the reference level (lowest effluent concentration target value or highest efficiency target value from Table 1) that could lead to 95 per cent of compliance for one or more treatment plants. These reference levels can be considered the most stringent target values, within those specified in Table 1, achievable by the systems investigated. Table 3 presents these values, considering the higher levels of compliance in terms of the effluent concentration and removal efficiency (95% compliance with the reference level).

For instance, the best performance observed for the activated sludge processes (AS) was obtained by the plants that achieve, in 95% of the collected samples, the following effluent concentration targets: BOD = 20 mg/L, COD = 50 mg/L, TSS = 40 mg/L, TN = 20 mg/L, TP = 3 mg/L and

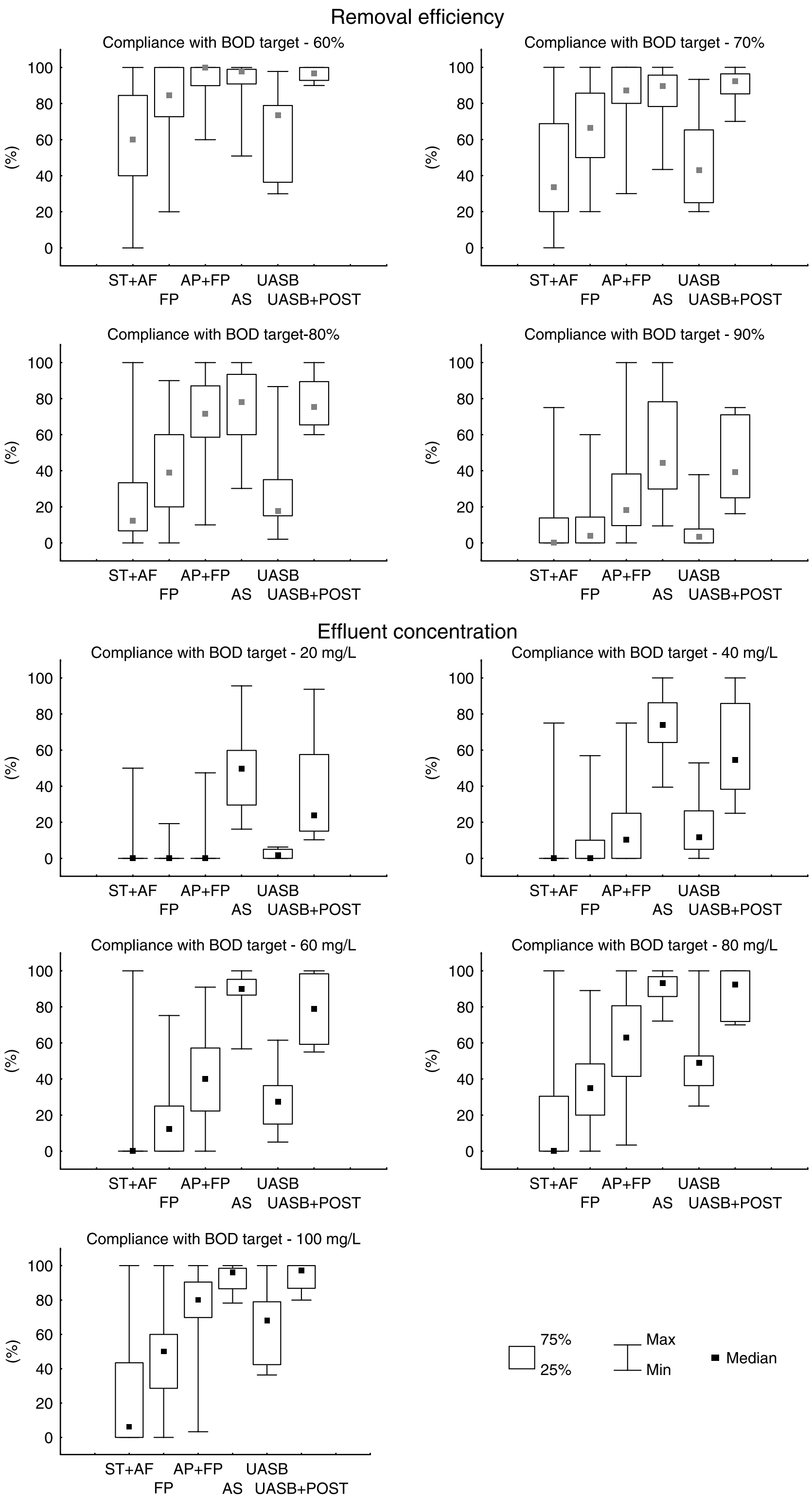

Figure 1 | Mean percentage of the compliance with the hypothetical quality targets, considering effluent BOD concentrations and removal efficiencies (166 WWTP).

Table 3 | Most stringent effluent quality targets achieved by the plants that were able to comply with the targets investigated (compliance = 95%)

Targets		Unit	ST + AF	FP	AP + FP	AS	UASB reactor	UASB + POST
Effluent concentration	BOD	(mg/L)	60	100	80	20	80	40
	COD	(mg/L)	200	–	150	50	200	150
	TSS	(mg/L)	60	100	–	40	80	20
	TN	(mg/L)	–	–	–	20	–	*
	TP	(mg/L)	–	4	5	3	5	4
	FC	(NMP/100 mL)	10^6	10^5	10^6	10^4	–	10^5
Removal efficiencies	BOD	(%)	80	60	90	90	60	80
	COD	(%)	75	55	65	85	55	65
	SS	(%)	80	70	60	80	70	80
	TN	(%)	–	20	60	40	–	*
	TP	(%)	–	40	40	60	–	20
	FC	(Log Unit)	–	2	1	2	–	4

–None of the targets was achieved; * Data not available for analysis.

FC = 10^4MPN/100 mL. The most stringent target, in terms of removal efficiency, achieved by the AS was: BOD = 90%, COD = 85%, TSS = 80%, TN = 40%, TP = 60% and FC = 2 log unit.

In general, a great variability was noticed in the effluent concentrations and in the removal efficiencies, considering all the analyzed constituents and all the treatment technologies. Some plants were capable to achieve very stringent standards, adopted by developed countries, such as AS process (BOD = 20 mg/L) and UASB + POST (TSS = 20 mg/L), showing that there are no technological limitations for wastewater treatment in Brazil, especially given the very favourable climatic conditions for biological treatment. However, most technologies showed a poor performance, and some of them were not capable to achieve even more relaxed standards, compared with those adopted in developed countries. It is believed that there are other non-technical factors, such as the level of process control and the attention to operational and maintenance requirements, which are influencing the ability of these processes to meet expected levels of performance. A detailed analysis on the possible causes of the variability in the performance is discussed in Oliveira & von Sperling (2005).

A further interpretation of Table 3, still using data from the plants that were able to comply with the targets investigated (compliance = 95%), leads to Table 4. In this table, two values are adopted for each constituent: (i) the concentration or removal efficiency that can be achieved by all six technologies and (ii) the best concentration or removal efficiency achievable by the most efficient technology. The former may set a

Table 4 | Effluent concentrations achievable by all six technologies or at least by one of the technologies (based on the plants that were able to achieve 95% compliance with the targets investigated)

Targets		Unit	Value achievable by all six technologies	Value achievable by the best technology
Effluent concentration	BOD	(mg/L)	100	20
	COD	(mg/L)	200	50
	TSS	(mg/L)	100	20
Removal efficiencies	BOD	(%)	60	90
	COD	(%)	55	85
	SS	(%)	60	80

Based on data from Table 3.

Table 5 | Typical and observed effluent concentrations (considering the most stringent effluent quality targets achieved by the plants)

	Literature values†						Observed values in the study					
Post treatment	BOD	COD	TSS	TN	TP	FC	BOD	COD	TSS	TN	TP	FC
ST + AF	60	200	60	–	–	10^6	60	200	60	–	–	10^6
FP	80	200	90	–	–	10^6	100	–	100	–	4	10^5
AP + FP	80	200	90	–	–	10^5	80	150	–	–	5	10^6
AS	20	100	30	–	–	10^6	20	50	40	20	3	10^4
UASB	100	200	90	–	–	–	80	200	80	–	5	–
UASB + aerated filter	40	100	30	–	–	10^6	–	–	80	*	*	–
UASB + anaerobic filter	60	200	60	–	–	10^6	40	200	20	*	*	10^6
UASB + trickling filter	40	100	30	–	–	10^6	60	150	40	*	*	*
UASB + flotation unit	40	100	30	–	–	10^6	40	100	60	*	4	*
UASB + facultative pond	80	150	60	–	–	10^6	100	–	100	*	4	10^5
UASB + maturation pond	60	200	90	20	–	10^3	60	250	–	*	4	10^5

†Average effluent concentrations considered typical by the technical literature (Von Sperling & Chernicharo 2002 and 2005).
–None of the targets was achieved; * Data not available for analysis.

realistic basis for specifying discharge standards that may be achievable by treatment processes commonly applied in developing countries, and the latter may be a basis for setting up discharge standards based on the best available technology adopted in developing countries. Of course more sophisticated treatment processes do exist and are capable of achieving better performance, but this analysis takes into consideration only typical treatment processes frequently adopted in developing countries. Table 4 has been constructed only for BOD, COD and SS, since the treatment plants investigated had not been conceived to remove nutrients or coliforms (what could bias the judgement of best available technology).

Von Sperling & Chernicharo (2002, 2005), based on a literature review, present typical effluent concentrations and removal efficiencies achievable by different wastewater treatment processes. It is interesting to compare their proposals with the actual treatment performance, as derived in this study and presented in Table 3. The comparison is shown in Table 5, and substantial similarity is found in both approaches.

CONCLUSIONS

In general, the plants presented low percentages of compliance with the various quality targets analysed, in terms of all constituents. The best comparative performance was obtained by activated sludge (AS), in terms of BOD and COD standards and UASB reactor followed by several post-treatments (UASB + POST), considering TSS limits.

The average performance of some treatment technologies, in terms of achieving all standards, was lower than expected. However, good performances were obtained by individual plants from all technologies, showing that the poor results could not be attributed to the treatment processes per se but possibly to design, operational and maintenance problems.

Elements for setting up discharge standards in developing countries are presented, supported by the actual treatment performance found in the study. Two approaches may be adopted: (i) discharge standards that may be achievable by treatment processes commonly applied in developing countries and (ii) discharge standards based on the best available technology usually adopted in developing countries. It is a matter of choice for each country which approach should be adopted. However, a stepwise progression from the simpler approach to the more stringent one, to be achieved on a long-term basis, seems the most reasonable way for developing countries.

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