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Assessment of pond system performance in microbial water quality

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Summary

The microbial water quality of a pond system is typically assessed by measuring the concentrations of the indicator organisms such as E. coli or faecal coliforms (MEDA Water, 2005; NRMMC, EPHC & AHMC, 2006; WHO, 2006) at the inlet and outlet, so that the pathogen log removal value and effluent quality can be estimated. Unlike a conventional activated sludge system, the microbial water quality of a pond system is heavily dependent on environmental conditions such as temperature and sunlight intensity (Shilton, 2005). Another unique feature is that wastewater is treated within a pond system for at least a couple of weeks, and even up to several months prior to discharge, while treatment is generally less than one week in an activated sludge system (Shilton, 2005; Sustarsic, 2009). Seasonal variation in removal efficacy must therefore be characterized as part of the microbial water quality assessment. An appropriate way to estimate the pathogen log removal value is a two-step process following a Monte Carlo simulation approach. This involves (1) fitting a statistical probability distribution to the inlet and outlet concentration data, and (2) deriving the distribution of the differences between the log10 transformed inlet concentrations and the log10 transformed outlet concentrations by Monte Carlo simulation. This study also investigates the impact of the sample size and replicate samples on the estimation precision of pathogen removal. Our empirical assessment result indicates that the choice of the replicate samples within each sampling occasion has very limited effect on the estimation results.

Introduction

Waste stabilization ponds (WSPs) are man-made water bodies in which domestic and/or municipal, or pre-treated industrial wastewater, are treated by natural occurring processes. Major influence factors in WSPs include retention time, solar light intensity, temperature, microorganisms, and algae. A pond system refers to a typical WSP system as depicted in Figure 1.1. As of 2012, there are about 1200 to 1300 Wastewater Treatment Plants (WTP) in operation in Australia of which about 600 are pond systems (Geoscience Australia, 2013). It is estimated that pond-based WTPs service at least 600,000 Australian populations, particularly in small communities and the vast majority of remote localities. Of the public health protection requirements, the microbial hazard is the primary concern for the use of recycled water or due to the pollution to the receiving water bodies (Haas, et al., 2014; MEDA Water, 2005; NRMMC, EPHC & AHMC, 2006; Shilton, 2005; Toze, 2004; WHO, 2006). Therefore, routinely monitoring of the treated wastewater microbial quality is an essential task for any WTPs. However, the assessment of wastewater treatment performance in microbial quality is challenging in practice for many reasons some of which are common to any treatment system and some that are particularly relevant for WSPs.

A fundamental problem in assessing performance is that a great variety of pathogens can occur in raw sewage, and their concentrations are extremely variable. Four main categories of pathogen (bacteria, viruses, protozoan parasites, and helminths) are frequently present in faecally-contaminated wastewaters. In practice, however, only indicator organisms (e.g., Escherichia coli or Thermotolerant coliform) have been routinely monitored, with the monitoring of pathogens in wastewater occurring as research activities rather than routine monitoring (NRMMC, EPHC & AHMC, 2006; Shilton, 2005; WHO, 2006). This is because most pathogens are difficult and comparatively expensive to measure (Haas, et al., 2014; Shilton, 2005; Toze, 2004). Another special feature of pond systems that further adds to the complexity is that pond performance is highly related to environmental and hydraulic conditions and the wastewater retention time in the system is much longer (Shilton, 2005). This implies that (1) temporal variation cannot be ignored, and that (2) a single value deterministic approach is unlikely to work well in the assessment of the pond performance in microbial water quality.

This study aims to highlight the difficulty and some unique features in assessment of microbial quality for pond systems. Empirical assessment results are presented based on statistical analysis on data collected from a pond-based WTP in NSW, Australia.

Methods/Materials

- The microbial quality data from a pond-based WTP in NSW, Australia, are used for analysis in this study (Kozak, 2014).
- Log removal value (LRV) is defined as: LRV = log10(inlet concentration) – log10(outlet concentration) (Haas, et al., 2014; NRMMC, EPHC & AHMC, 2006; WHO, 2006).
- A Monte Carlo simulation approach is featured by the extensive use of random numbers which are generated from probabilistic distributions in the computational process and it is used to characterize the pathogen log removal value and the impact of sample size and replicate samples on estimation precision. The statistical data analysis was performed using the free statistical software R (R Development Core Team, 204).
- The LRV is estimated by Monte Carlo simulation which performs the calculation of log10(influent concentration distribution) – log10(effluent concentration distribution) using the computer software @Risk (Palisade Corporation, 2014).

Results and discussions

The pathogen removal in a pond system is due to some very complex physical-chemical-biological (natural) processes with factors including temperature, retention time, sunlight, sedimentation, etc. Removal of bacteria and viruses mainly happens in the facultative and maturation ponds (Shilton, 2005). Parasite removal occurs predominantly through sedimentation. The pond effluent concentration is expected to show strong seasonal patterns. Table 1.1 provides a good empirical evidence of seasonal differences in microbial abundance in ponds. The lowest effluent concentrations of thermotolerant coliform occurred in summer, while the highest concentrations were observed in spring and it can be shown that this difference is statistically significant (Kozak, 2014). Wastewater retention time is approximately 60 days in the pond (Kozak, 2014) which is quite typical in a WSP system. As such, pond performance (in terms of log removal) was considered by treating both the influent and effluent concentrations as random variables (using indicator species as surrogate for pathogens). Therefore, the estimation of log removal value (LRV) was characterized by a probability distribution rather than a single summary statistics, e.g., mean or median. This analysis allows us to characterize the pond performance using different assessment criteria. For example, we may use median LRV to represent a typical condition or the 5th percentile to represent a worst scenario in the subsequence health risk assessment analysis. Finally, as shown in Figure 1.2, for a reliable estimation of the log removal performance of a pond system (e.g., probability of coverage > 0.9), at least 20 water samples are needed which should be representative of the temporal variation patterns. The tightly clustered pattern of the dotted-curves indicates that the choice of the replicate samples within each sampling occasion has very limited effect on the estimation of the true log removal performance.

Conclusion

Monitoring microbial water quality is essential for assessing pond system performance. However, there is no simple solution for this job. The sampling scheme for the assessment of a pond system should take into account temporal variation. A Monte Carlo simulation approach is an appropriate tool to model the stochastic features inherent in the assessment process. It is concluded that the sample size plays a dominant role in achieving a good precision for estimating log removal values in this particular case.

Table 1.1 T A summary of the effluent microbial quality from a wastewater treatment plant (pond system) in NSW, Australia [3]

Thermotolerant coliform, three-year monitoring period (CFU/100mL)	Summer	Autumn	Winter	Spring	Overall
50th percentile (median)	3	20	34	52	28
95th percentile	50	213	125	220	159

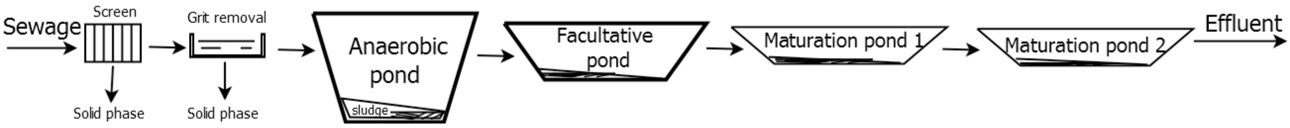

Figure 1.1 A schematic showing a typical waste stabilization pond system

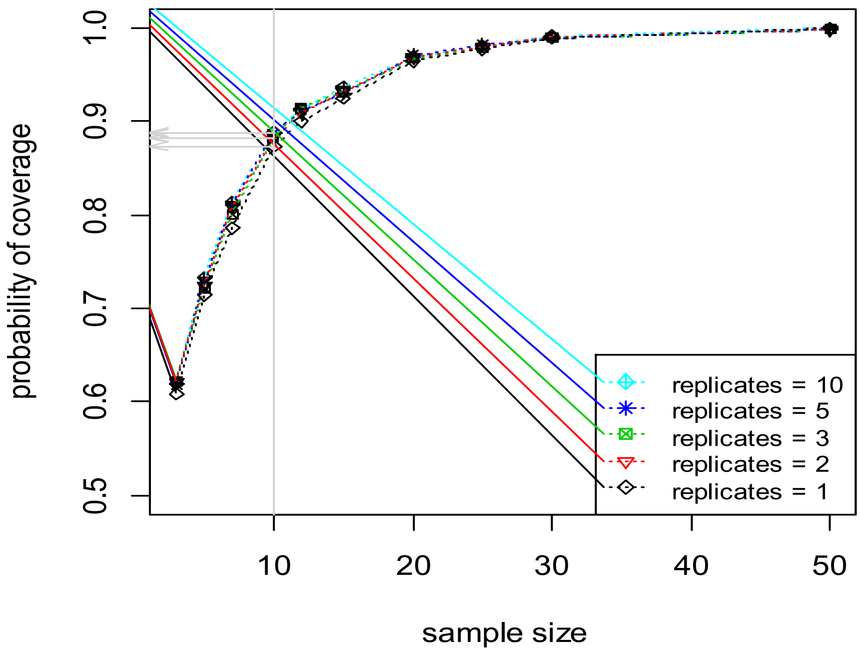

Figure 1.2 Impact of sample size and replicate samples on probability of coverage. The probability of coverage is defined as the probability that the estimated median log removal value (LRV) is within the range of true median LRV ± 0.5.

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