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# Temporal variation of faecal indicator bacteria in tropical urban storm drains

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ABSTRACT

Human faecal contamination poses a widespread hazard for human health. In urban areas, sewer leakage may be an important cause of faecal pollution to surface water. Faecal indicator bacteria (FIB) are the most widely used indicators to monitor surface water quality. However, assessing whether a water body is meeting water quality criteria is made difficult by the high variability of FIB concentrations over time. In this study, the variation of FIB concentration in surface water from tropical urban catchments is investigated. Eleven urban sub-catchments were sampled hourly over 24-hr and samples analysed for FIB. It was found that FIB show a diurnal pattern that is characterised by daytime FIB concentrations that are significantly higher than nighttime FIB concentrations. This observed diurnal variation of FIB closely follows that of sewer flows and contrasts with observations in rural streams where FIB concentrations are known to be low in the daytime and high during the night. Field tracer tests provide qualitative evidence of sewage exfiltration and transport to drains via preferential flow paths. The diurnal FIB variation and field tracer tests indicate the likelihood of surface water contamination due to leaking sewers. The results further suggest that contamination of surface-water drains is likely a widespread problem in tropical urban areas due to extensive drainage networks and the persistence of FIB under tropical conditions. Because of FIB variation over time, the time at which samples are collected is important in being able to capture the daily maximum and minimum FIB concentrations. The Kruskal–Wallis test shows that hourly sampling from 04:00 to 07:00 and from 12:00 to 15:00 results in significantly different FIB concentration (minimum and maximum, respectively). Furthermore, the Wilcoxon-Mann-Whitney test shows that sampling at 12:00 and 14:00 results in significantly higher FIB concentrations, while sampling at 05:00 and 04:00 or 05:00 and 06:00 results in significantly lower FIB concentrations, than sampling at other hours of the day.



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## 1. Introduction

Human faecal contamination poses a widespread hazard for human health (Arnone and Walling, 2007). For surface waters in urban catchments, leaking sewers can be an important cause of faecal pollution of the drainage system arising as a result of ageing or damaged sewer lines (Held et al., 2006; Whitlock et al., 2002). Sewage from leaking sewers may exfiltrate through unsaturated soil into groundwater and is finally discharged into surface waters such as at shorelines (Boehm et al., 2003, 2004) or storm drains (Sauer et al., 2011; Sercu et al., 2009, 2011).

The presence and concentration of faecal indicator bacteria (FIB) are often used to assess whether a water body meets water quality standards. FIB are non-pathogenic organisms that are believed to be associated with pathogenic organisms but are more easily measured. However, the assessment of water quality for bacterial contamination is made difficult by the high variability of indicator bacterial concentrations over time. Many water quality monitoring programs focus primarily on low-frequency dry-weather sampling (Traister and Anisfeld, 2006). Leecaster and Weisberg (2001) showed that sampling frequency affects the number of high FIB events that are detected. Traister and Anisfeld (2006) suggested the importance of sampling programs that capture a fuller range of stream conditions. Besides sampling frequency, sample collection time can dramatically influence the concentration of indicator bacteria detected (Boehm et al., 2002) and hence different sample collection times could result in different management decisions (Enns et al., 2012). Boehm et al. (2002) and Kwasi et al. (1999) recommended that ideally samples should be collected in the early morning before sunlight has had a chance to reduce FIB concentrations. However, it is important to note that those studies sampled surface waters at beaches that are exposed to sunlight. Therefore, when the surface water is not exposed to sunlight (such as in covered drains or open drains that are shaded by trees or buildings), the suggestion to sample in the early morning period may not be applicable. Some studies have observed a diurnal cycle of FIB at beaches (Boehm et al., 2002; Enns et al., 2012) and streams (Desai and Rifai, 2013; Traister and Anisfeld, 2006) caused by sunlight-induced die-off, with higher concentrations in the night and lower in the afternoon. However, Desai and Rifai (2010) point out the complexity of this phenomenon and its dependence on flow, turbidity, total suspended solids, temperature, location and land use in the catchment.

Sercu et al. (2009) sampled storm drains during dry weather in Santa Barbara, CA, USA and reported the exclusive occurrence of high human-specific *Bacteroides* marker with high FIB concentrations. Assuming similar behaviour, high FIB concentrations in covered and well shaded storm drains should indicate human faecal contamination such as from leaking sewers. To the best of the authors' knowledge, this possibility has not been investigated in tropical, urban storm drains. Two studies conducted in Singapore detected perfluorochemicals such as perfluorooctane sulfonate in 1–156 ng/L (Nguyen et al., 2011) and emerging organic contaminants including pharmaceuticals in the ng/L range (Xu et al., 2011) in surface drains and attributed the presence of these contaminants to non-point sources which include leaking sewer lines. Therefore, the objectives of this study were to investigate: (i) how FIB concentrations in tropical urban drainages vary on a daily time scale where there is only a slight variation between daytime and nighttime temperatures and where there is little effect of sunlight because the drainages are mostly covered or well shaded, (ii) if leaking sanitary sewers are a major influence on FIB concentrations in urban storm drains and (iii) how water quality monitoring practice should be adapted in order to take into account diurnal variations in FIB concentrations.

## 2. Materials and methods

### 2.1. Site description

This study was conducted at eleven urban sub-catchments in Singapore (Fig. 1). The climate in Singapore is tropical with annual rainfall of approximately 2200 mm with no distinct wet or dry seasons and daily mean temperature varying over a narrow range between 26.0 °C and 27.7 °C through the twelve months of the year (NEA, 2014). Table 1 provides land-use information for the eleven sampling sites; land use is predominantly residential. The sub-catchments were delineated using ArcGIS Desktop 10 (Esri, Redlands, CA, USA) and land-use proportion was determined using GIS land-use data provided by the Public Utilities Board (PUB), Singapore. Six of the sub-catchments are mainly high-density residential areas consisting of high-rise apartment buildings while the other five sub-catchments are mainly low-density residential areas consisting of single-family housing units.

### 2.2. Sampling campaign

Fourteen sets of 24-hr FIB samples were collected at the eleven sampling sites during dry weather (baseflow) between January and July 2012 (inclusive). Sampling during dry-weather conditions eliminates surface runoff as a potential source of contamination. The sampling dates are summarised in Table S1. Sampling was conducted three times at site A and twice at site H on different days to see if diurnal patterns were repeatable. The patterns at Site H were repeated very closely between the two sampling series. Two of the three sampling series at Site A showed similar (typical) patterns; one showed atypical fluctuations. Sampling mostly started at 20:00, with the exception of site A, site D and site I which started at 08:00 instead. Most of the 24-hr sets of samples were collected using two Avalanche® refrigerated auto-samplers (Teledyne Isco, Lincoln, NE, USA). The samples collected by the auto-samplers were stored in the field in a refrigerated compartment at 4 °C for not more than 22 hr after the start of sampling. A HOBO® U10 temperature data logger (Onset Computer Corporation, Cape Cod, MA, USA) was installed in the refrigeration compartment to ensure that the refrigeration system was in good working order. Each auto-sampler drew samples from the drainage channels via a dedicated sampling line. In operating the auto-sampler, precaution was usually taken to prevent contamination from water left in the sampler tubing from the prior sample by pre-rinsing the sampling lines before