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Twenty five years of beach monitoring in Hong Kong: A re-examination of the beach water quality classification scheme from a comparative and global perspective

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ABSTRACT

Hong Kong's beach water quality classification scheme, used effectively for > 25 years in protecting public health, was first established in local epidemiology studies during the late 1980s where *Escherichia coli* (*E. coli*) was identified as the most suitable faecal indicator bacteria. To review and further substantiate the scheme's robustness, a performance check was carried out to classify water quality of 37 major local beaches in Hong Kong during four bathing seasons (March–October) from 2010 to 2013. Given the enterococci and *E. coli* data collected, beach classification by the local scheme was found to be in line with the prominent international benchmarks recommended by the World Health Organization and the European Union. Local bacteriological studies over the last 15 years further confirmed that *E. coli* is the more suitable faecal indicator bacteria than enterococci in the local context.

1. Introduction

Beach water quality classification systems are commonly adopted worldwide as beach management tools to assess public health risk associated with swimming in bathing waters. To quantify beach water quality, one may consider analysing the waters for the presence of specfic pathogens of concerns or index representatives, as it is impractical to look for each and every pathogen potentially present in water (Ashbolt et al., 2010). Furthermore, many pathogens under environmental stresses may not grow in culture media nor are economic methods available. Most importantly, human enteric viruses from sewage are seen as the major bather health hazards (Sinclair et al., 2009), with the most often identified as *Norovirus* that has yet to be cultured. In general, it is very difficult and expensive to assay infectious enteric viruses, hence the lack of routine monitoring for enteric viruses in recreational waters globally. On the other hand, faecal indicator bacteria (FIB) such as *Escherichia coli* (*E. coli*) and enterococci, which reside in the gastrointestinal tracts of warm-blooded animals, are usually abundant in faecally-polluted waters. Hence FIB are commonly used to assess the microbiological water quality of recreational waters for faecal pollution (Cabelli et al., 1983; Wade et al., 2006). Since these FIB may colonise sediments (Davies et al., 1995) and are present in faecal sources of lower health risk to recreations (Schoen et al., 2011), it is important to understand the likelihood for human sewage pollution when interpreting FIB data (Soller et al., 2015).

In terms of international standards, the World Health Organization (WHO) published the "Guidelines for Safe Recreational Water Environments" (WHO's Guidelines) in 2003 (WHO, 2003) with an Addendum in 2009. The guidelines recommended jurisdictions to conduct microbial water quality assessment (MWQA) and sanitary inspections to classify the likelihood for human sewage versus other faecal sources in bathing waters. The MWQA classifies the waters into four categories: "A", "B", "C" and "D", representing different risks of contracting gastrointestinal illnesses and acute febrile respiratory illnesses (AFRI). The classification is based on the 95th percentile value of intestinal enterococci concentration (a subgroup of the faecal streptococci known generally as enterococci) calculated using a rolling 5-year data set of at least 100 samples by the Hazen Formula (Table 1). The swimming associated health risks were obtained from the randomized controlled trails on bathers in temperate waters of northern Europe (Kay et al., 1994; Fleisher et al., 1996; Kay et al., 2004). Sanitary inspections should also be conducted to identify sources of faecal pollution,

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Table 1
WHO's Guideline values for microbial quality assessment of recreational waters (coastal waters/seawater).

Microbial water quality assessment category	95th percentile value of intestinal enterococci/100 mL	Estimated risk per exposure ([a])
A	≤40	< 1% GI illness risk; < 0.3% AFRI risk
B	41–200	1–5% GI illness risk; 0.3–1.9% AFRI risk
C	201–500	5–10% GI illness risk; 1.9–3.9% AFRI risk
D	> 500	> 10% GI illness risk; > 3.9% AFRI risk

The dose-response curve in Kay et al. (1994) assumes no further illness outside the range of the data of the epidemiological study (i.e., above 158 intestinal enterococci/100 mL).

[a] GI – Gastrointestinal Illness; AFRI – Acute Febrile Respiratory Illness.

including sewage discharges, riverine discharges, bathers shedding and animal inputs, that could potentially affect the beach water in the vicinity. The bathing beaches will then be classified into “Very good”, “Good”, “Fair”, “Poor” or “Very poor” based on the combined results of MWQA and sanitary inspection (Table 2).

Another major international guideline for recreational water classification is the European Union (EU)'s Directive 2006/7/EC (the EU's Scheme) which classifies coastal waters into “Excellent quality”, “Good quality”, “Sufficient” or “Poor” with reference to the abundance of both intestinal enterococci and *E. coli* measured over four bathing seasons (EU, 2006) (Table 3). The EU's Scheme was developed based on the epidemiology studies in marine waters by Kay et al. (1994) and freshwater by Wiedenmann et al. (2006). Subsequent epidemiology studies in North America further supported the value of FIB in predicting health risk for sewage-impacted waters. This also resulted in the revision of ambient water quality criteria by the United States Environmental Protection Agency (U.S.EPA) (2012) to also include enterococci by quantitative polymerase chain reaction (qPCR). Sanitary survey information and quantitative microbial risk assessment (QMRA) useful for setting site-specific FIB criteria for non-sewage-impacted beaches were also discussed.

Table 2
WHO's suggested classification matrix for faecal pollution of recreational water environment.

Sanitary inspection category	Microbial water quality assessment category (95% percentile intestinal enterococci/100 mL)			
	A (≤40)	B (40–200)	C (201–500)	D (> 500)
Very low	Very good	Very good	Follow up (*1)	Follow up (*1)
Low	Very good	Good	Fair	Follow up (*1)
Moderate	Good (*2)	Good	Fair	Poor
High	Good (*2)	Fair (*2)	Poor	Very poor
Very high	Follow up (*2)	Fair (*2)	Poor	Very poor

*1 – implies non-sewage sources of faecal indicators (e.g., livestock), and this should be verified as suggested by the WHO's Guidelines.
*2 – indicates possible discontinuous/sporadic contamination (often driven by events such as rainfall). WHO indicates that this is most commonly associated with Combined Sewer Overflow presence. These results should be investigated further and initial follow up should include verification of sanitary inspection category and ensuring samples recorded include “event” periods. WHO's guidelines suggests to confirm analytical results and review possible analytical errors.

Table 3
Classification criteria for coastal and transitional waters under the EU's Scheme.

Parameter	Excellent quality	Good quality	Sufficient
Intestinal enterococci (cfu/100 mL)	100[a]	200[a]	185[b]
E. coli (cfu/100 mL)	250[a]	500[a]	500[b]

[a] Based upon a 95-percentile evaluation.
[b] Based upon a 90-percentile evaluation.

Hong Kong's existing beach water quality monitoring programme has been implemented by the Environmental Protection Department (EPD) for > 25 years since 1992. The programme was designed to assess the water quality of bathing beaches and their compliance with the bacteriological Water Quality Objective (WQO) (i.e. *E. coli* standard of 180 cfu/100 mL), which was established through a scientific approach according to the results of the comprehensive epidemiology studies jointly conducted by the EPD and The University of Hong Kong (HKU) in late 1980s (Cheung et al., 1990, 1991; Kueh et al., 1995). It was one of the first major epidemiology investigations conducted in subtropical waters, and has been extensively cited in open literature during the research and development of microbiological water quality guidelines (Prüss, 1998). The epidemiology studies were designed with reference to local pollution and hydro-meteorological characteristics, as well as guidelines provided in the WHO/United Nations Environment Programme (UNEP) report (WHO/UNEP, 1977) and the then U.S.EPA ambient water quality criteria recommendations for recreational waters (U.S.EPA, 1986). It was found that, *E. coli,* among the nine microbial indicators examined (i.e. faecal coliforms, *E. coli, Klebsiella* spp., faecal streptococci, enterococci, staphylococci, *Pseudomonas aeruginosa*, total fungi and *Candida albicans*), was the only indicator that showed a significant correlation with highly credible gastrointestinal (HCGI) illness rate hence the best FIB in reflecting the risk of contracting swimming-associated illnesses at Hong Kong beaches. Subsequently, Hong Kong's beach water quality monitoring programme was developed based on *E. coli* as the only indicator in 1988. Currently, 44 beaches (Fig. 1) are monitored by EPD for their long-term water quality trend, and for reference by the beach management authority to decide whether a beach should be open or closed for swimming due to changes in water quality.

Hong Kong beach water quality classification adopts a dual system: the annual ranking system and the weekly grading system (Table 4). Under the annual ranking system, beaches are classified into “Good”, “Fair”, “Poor” or “Very Poor” according to their annual geometric mean (AGM) of *E. coli* concentrations in the beach water over the bathing season from March to October, with a sampling interval of 3–14 days. Beaches in the first two categories, i.e. “Good” and “Fair”, meet the WQO for bathing beaches (AGM of *E. coli* ≤180 cfu/100 mL). Beaches having AGM of *E. coli* concentrations > 180 and 610 cfu/100 mL, respectively are ranked “Poor” and “Very Poor”, and may warrant closure in the next bathing season by the beach management authority to safeguard public health. Under the weekly grading system, beaches are classified into four grades (1 to 4) according to the geometric mean of *E. coli* concentrations measured in the five most recent sampling occasions, typically covering a month time, to inform more recent bacteriological water quality of the beaches. Following a review of the EPD's beach monitoring programme conducted in 1999 (Ho, 2001), the weekly beach grading system was slightly modified to give a beach the worst grade (Grade 4) when the last *E. coli* concentration exceeds 1600 cfu/100 mL with a view to alerting the public on any sudden deterioration of water quality. The threshold value of 1600 cfu/100 mL was derived based on earlier local epidemiology study, assuming a single sample limit not exceed 75% confidence level of the geometric mean value would indicate the same level of illness rate. The above made reference to the recommendation in the U.S.EPA criteria (U.S.EPA, 1986) in determining an appropriate site-specific single sample *E. coli* limit, beyond which immediate investigation and re-sampling will be required to safeguard health of swimmers.