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Health effects of beach water pollution in Hong Kong

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SUMMARY

Prospective epidemiological studies of beach water pollution were conducted in Hong Kong in the summers of 1986 and 1987. For the main study in 1987, a total of 18741 usable responses were obtained from beachgoers on nine beaches at weekends. The study indicated the overall perceived symptom rates for gastrointestinal, ear, eye, skin, respiratory, fever and total illness were significantly higher for swimmers than non-swimmers; and the swimming-associated symptom rates for gastrointestinal, skin, respiratory and total illness were higher at 'barely acceptable' beaches than at 'relatively unpolluted' ones. *Escherichia coli* was found to be the best indicator of the health effects associated with swimming in the beaches of Hong Kong. It showed the highest correlation with combined swimming-associated gastroenteritis and skin symptom rates when compared with other microbial indicators. A linear relationship between *E. coli* and the combined symptom rates was established. Staphylococci were correlated with ear, respiratory and total illness, but could not be used for predicting swimming-associated health risks. They should be used to complement *E. coli*. The setting of health-related bathing-water quality standards based on such a study is discussed.

INTRODUCTION

Swimming is Hong Kong's most popular summer recreation. There are 42 coastal beaches gazetted for such a purpose. No fewer than 18 million person-visits are being recorded at these beaches each year. Popular beaches may receive up to 1·5–3 million visitors in a season, and 50000 or more on a single day. In connection with protecting the public from waterborne infections, the most important beach-water quality standards are microbiological in nature. To enable these standards to be met, expensive sewage treatment and disposal facilities near bathing beaches have been built, and sewerage schemes at a total cost of around HK$700 million are being planned.

First adopted in 1981, the existing bacterial water quality objective for the

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bathing beaches in Hong Kong is as follows: 'The level of *Escherichia coli* should not exceed 1000 per 100 ml, calculated as the running median of the most recent 5 consecutive samples. Samples should be taken 3 times in any one month at intervals of between 3 and 14 days during the bathing season' [1]. This standard was set by modifying the 'interim' acceptability criterion recommended by a WHO/UNEP report [2], at a time when epidemiological information on the health effects of beach water pollution was very sparse indeed.

Subsequently, an annual acceptability standard of 60% compliance with the 1000 *E. coli* per 100 ml criterion was also adopted in Hong Kong. Only those beaches which could not attain this minimum standard were 'closed' by the two municipal councils, the management authorities for gazetted bathing beaches. Warning signs would be erected at these beaches, and life-guards as well as shower facilities would be withdrawn, so as to discourage the bathers from entering into the water.

The existing Hong Kong beach-water quality standards, as well as the WHO and EEC standards, were set based on judgement and were not supported by data on health effects due to swimming exposure. The WHO and UNEP reports [2, 3] putting forward the 'interim' acceptability criterion recommend epidemiological studies of beach water pollution be undertaken by individual countries, so that health-related bathing-water criteria could be developed.

There are two types of epidemiological investigations related to beach water pollution, retrospective and prospective studies. In a retrospective study, individuals who have developed a disease are compared with a group of similar individuals who did not, with respect to exposure to bathing waters. The usefulness of such type of studies for developing health-related beach-water criteria is limited, as they are unlikely to yield dose–response relationships [2]. It is also not possible to use this method for studying every possible health consequence of swimming exposure, and one would need to identify the diseases that are to be investigated at the outset of the study. These were poliomyelitis and enteric fever in the well known study by the Public Health Laboratory Service (PHLS) [4].

On the other hand, retrospective analysis of recreational waterborne outbreaks is important for revealing the specific disease entities which could be transmitted through swimming in faecally polluted waters. For instance, there were studies indicating that enterovirus-like illnesses (particularly those caused by coxsackieviruses) were swimming-related [5–7]. Other studies also provided evidence that swimming in polluted freshwater beaches could be linked with outbreaks of hepatitis A [8], shigellosis [9, 10], and Norwalk virus gastroenteritis [11, 12].

In a prospective study, groups differing in their exposure to bathing water are followed up, and illness incidence is compared in relation to such exposure. There were two such studies based on which health-related beach-water quality standards were set. The first one was undertaken by the US Public Health Service during 1948–50, in which illness information from 22264 participants was obtained [13]. It was found at a freshwater Chicago beach that symptomatic rates for ear, eye, skin, respiratory and gastrointestinal illnesses were significantly higher in individuals who swam on 3 successive days when the geometric mean 'total coliform' density was 2300 per 100 ml, than in swimmers who swam on 3 successive days when the mean coliform density was 43 per 100 ml. In the Ohio River study, a detectable health effect was found amongst river swimmers; they displayed 32% more gastrointestinal illness than might be expected by chance. The median total coliform density in the stretch of the river was 2700 per 100 ml. No relationships between total coliform levels and swimming-related illness were observed at marine beaches. Based on these findings, the then Federal Water Pollution Control Administration arrived at a standard of 200 'faecal coliforms' per 100 ml for both marine and freshwater beaches in 1968 [14]. This criterion was heavily criticized – in respect of the inadequacy in the design of the original studies; the paucity of valid epidemiological data; the ways in which the criterion was derived; and the microbial indicator used [4, 15, 16].

The second study was conducted by the workers of US EPA during 1973–82, with a view to correct the deficiencies of the previous survey. The study, this time on marine beaches, involved obtaining usable responses from 26686 beachgoers at five beaches [16, 17]. It was found gastrointestinal symptoms were both swimming-associated and pollution-related. Enterococcus was the best indicator as it showed the highest correlation with swimming-associated gastroenteritis symptom rates and a linear relationship was established. The US workers also concluded the previous use of the criterion of a geometric mean faecal coliforms density of 200 per 100 ml would have caused an estimated 19 cases of acute gastroenteritis disease per 1000 swimmers at marine beaches, and the US community has 'unknowingly accepted' this swimming-associated health risk. The geometric mean enterococci density corresponding to this historically accepted risk is 35 per 100 ml; and this is the new standard for marine beaches recently recommended by US EPA in 1986 [18], 18 years after the previous standard was set. Similar studies were conducted at four marine beaches in Alexandria, Egypt (which are generally more polluted than the US beaches), in which usable responses were obtained from 23080 beach visitors [16]. Strong association of diarrhoea and vomiting symptoms to *E. coli* as well as enterococci densities was observed. Another study was undertaken at four US freshwater beaches with 38140 usable responses obtained [19, 20]. There was strong correlation between 'highly credible' gastrointestinal symptoms and *E. coli* as well as enterococci; and both *E. coli* and enterococci standards have been recommended for the freshwater beaches of USA [18].

Subsequent prospective studies of similar nature undertaken by workers in Canada [21, 22], Israel [23] and England [24] were of smaller scale when compared to the US EPA studies; and their findings have not been used for setting beach-water quality standards. The number of beachgoers interviewed at the freshwater beaches in Canada and the coastal beaches in Israel and England were 4537, 2036 and 1903, respectively.

This paper reports the findings of the prospective epidemiological studies of beach water pollution undertaken in Hong Kong in 1986 and 1987. It firstly ascertains whether swimming in the subtropical beach waters of Hong Kong carries an increased risk of illness; and whether swimming in faecally polluted beaches poses higher health risks than in less polluted ones. Secondly, it determines which microorganism is the best indicator of the health effects of beach water pollution; and whether a quantitative relationship between the densities of this indicator organism in beach waters and swimming-associated health risks can be established. Finally, the use of such a relationship for setting health-related bathing-water quality standards in Hong Kong is discussed.

METHODS

The method for the study was based on the protocol recommended by WHO/UNEP reports [2, 25], with some modifications to suit local conditions.

The study was conducted in two phases. The initial phase (pretest) was undertaken at four very popular beaches, during six weekends in July and August of 1986. The purpose of this phase was to test the epidemiological techniques, and to provide preliminary estimates of the swimmer and non-swimmer (background) illness rates needed for estimating the sample size for the main study. The second phase study was carried out at nine popular beaches, over 11 weekends from June to September of 1987. This main study in 1987 was to provide the data for setting health-related bathing-water quality standards which suit the local conditions of Hong Kong.

For each phase, the studies undertaken were divided into two parts: epidemiological studies involving beach and follow-up telephone interviews; and intensive monitoring of the microbiological quality of beach waters over weekends.

Beaches under study

The pretest in 1986 was carried out at Repulse Bay, Stanley Main, Lido and Old Cafeteria Beaches. The nine beaches in the major study in 1987 were Repulse Bay, Deep Water Bay, Stanley Main, Shek O, Clear Water Bay, Lido, Butterfly, and Old and New Cafeteria. The location of these beaches is shown in Fig. 1. These beaches, with their levels of microbial pollution falling on a gradient, were selected based on the bacterial water quality data obtained over the years by the Environmental Protection Department of the Hong Kong Government.

Repulse Bay, Deep Water Bay, Stanley Main, Shek O, Clear Water Bay and Lido Beaches are polluted to different extent by human sewage discharged from submarine sewage outfalls nearby, or carried by stormwater drains running into the beaches. Old and New Cafeteria Beaches are contaminated by livestock wastes (mainly pig excreta) discharged from Tuen Mun Nullah. Butterfly Beach is affected by both Pillar Point submarine sewage outfall and Tuen Mun Nullah.

Water sampling

Subsurface water samples were collected from three sampling points (50–150 m apart, 1 m deep) at each beach under study, in locations with high densities of bathers. For each beach, this was carried out every 2 h from 9 am to 5 pm, on weekend days in which beach interviews were carried out. The samples were packed on ice, kept in the dark, and processed within 4–6 h after collection.

Microbiological analysis

A total of nine microbial indicators in beach water samples were analysed, namely faecal (thermotolerant) coliforms, *E. coli*, *Klebsiella* spp., faecal streptococci, enterococci, staphylococci, *Pseudomonas aeruginosa*, *Candida albicans* and total fungi. All these indicator organisms in beach water samples were enumerated using the membrane filtration method. The 0·75 μm Millipore HC membrane filters were used for testing faecal coliforms, *E. coli* and *Klebsiella* spp.; and the rest of the microorganisms were analysed by the 0·45 μm Gelman GN-6 membrane filters.

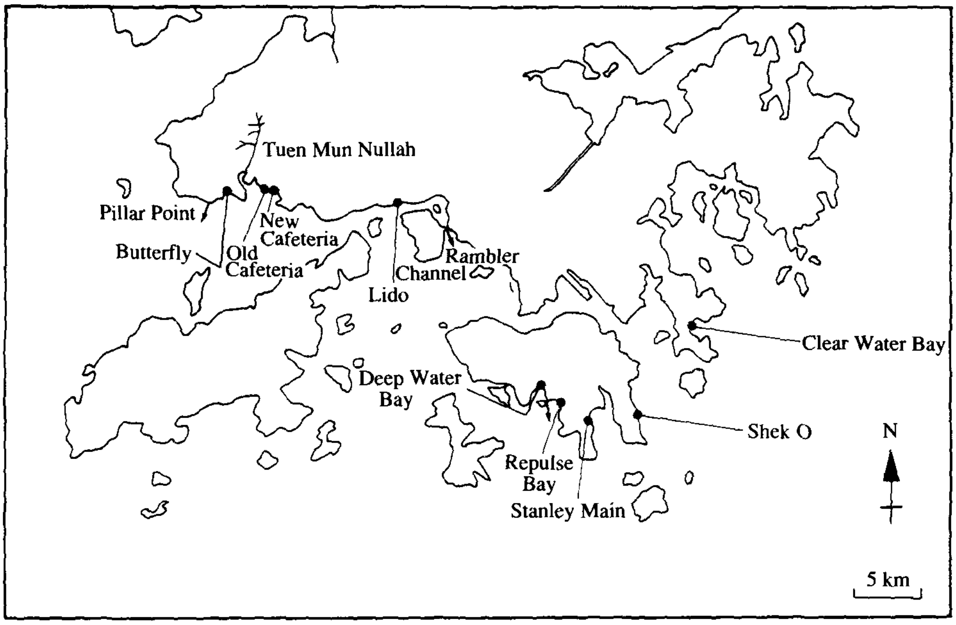

Fig. 1. Location of the nine bathing beaches under study in Hong Kong. ●, Beach; →, submarine outfall.

The faecal coliforms were counted as the yellow colonies on the mLS medium [26, 27], after incubation at 44 °C for 18 h. The colonies on the same membrane remaining yellow after the *in situ* urease test were enumerated as *E. coli* [28, 29]. The *Klebsiella* spp. were those yellow thermotolerant colonies which turned pink in the *in situ* urease test.

Faecal streptococci were analysed using the KF medium [30]; and for enterococci, the m-Enterococcus medium [31]. The VJP medium [32, 33] was used for enumerating staphylococci; the mPA-E medium [34, 35], for *Pseudomonas aeruginosa*; the mCA medium [36], for *Candida albicans*; and the MSTMEA medium [37], for total fungi.

Selected microbial colonies on the membranes had been confirmed by the API or VITEK identification systems.

The interviews

The beachgoers were first recruited at the beaches during weekends. Their names, addresses and telephone numbers were obtained. They were also asked about possible pre-trial illness, and pre-trial swimming activities in the week beforehand.

Follow-up telephone interviews were conducted the next day for soliciting information on water exposure while at the beach during the weekend. The respondents were asked when they had swum; and whether they had swum with head above water, or just wading without getting their head into the water. This was important in classifying the beachgoers as 'swimmers' or 'non-swimmers'. Further information on their demographic variables and on the type of food eaten at the beach was also solicited.

The beachgoers were again telephone interviewed 7–10 days afterwards, to see whether they had any illness developed, and to obtain information on the on-set time of the perceived symptoms and their duration. Possible post-trial mid-week swimming activities were asked about.

Definition of 'swimmers' and 'non-swimmers'

Swimming has been defined as having significant exposure of upper body orifices (i.e. the head) to beach water, in accordance with the recommendation of WHO/UNEP reports [2, 25]. 'Swimmers' therefore included individuals who entered the water and immersed their heads on the day of study, and also young children who did not actually swim in the strict sense of the word, but who spent time in the water or at the water's edge and whose faces were splashed by wave action or other means, thus affording a chance to ingest beach water. 'Non-swimmers' were those beachgoers who had not immersed their heads in beach water.

Symptoms and swimming-associated illness rates

The perceived symptoms reported were grouped into the following categories: gastrointestinal (GI), highly credible gastrointestinal (HCGI), ear, eye, skin, respiratory, and others (mainly fever and headache).

Gastrointestinal (GI) symptoms include vomiting, diarrhoea, stomach ache and nausea. 'Highly credible gastrointestinal' (HCGI) symptoms are defined as any one of the following: vomiting; diarrhoea with a fever or a disabling condition (remained home, remained in bed or sought medical advice); and nausea or stomach ache accompanied by a fever. Individuals in this perceived symptom category are considered to have acute gastroenteritis.

Ear symptoms include earache or discharge; and for eye symptoms, eye-sore, irritation or redness. Skin symptoms are mainly rashes, exclusive of sunburn. Respiratory symptoms cover sore throat, heavy cough, and running nose.

The swimming-associated illness rate (or swimming-related health risk) for each symptom category was obtained by subtracting the perceived illness rate for non-swimmers from that for swimmers. The relative risk (RR) was the ratio of the illness rates for swimmers to those for non-swimmers.

Statistical analysis

Statistical significance was analysed using the *t* test. STATGRAPHICS software was used for constructing deterministic regression models and testing their significance.

RESULTS

Pretest, 1986

A total of 6639 beachgoers were interviewed at the four beaches, and 5114 follow-up interviews were completed. The response rate was 77 %. Around 30 % of the beachgoing population swam in the mid-week before or after the weekend trials, and hence had multiple exposure to various beach or swimming-pool waters with varying microbiological quality. Their responses were excluded from the study. Amongst the 3549 usable responses, 73 % were from swimmers and the rest from non-swimmers. The perceived symptom rates for swimmers were higher than those for non-swimmers in the categories of GI, HCGI, eye, skin, fever and total illness. The swimming-associated gastroenteritis (HCGI) rates for various beaches were low, ranging from 0·5 to 3·1 per 1000 swimmers; and the overall rate was 1·3 per 1000 swimmers. An analysis of the pretest data indicated if significant difference in the symptom rates between swimmers and non-swimmers were to be obtained in the main study, at least 32800 beachgoers should be interviewed and 17700 usable responses obtained (type-one error, $\alpha = 5\%$; type-two error, $\beta = 10\%$).

Second phase study, 1987

Populations sampled

A total of 33083 beachgoers were preliminarily interviewed at the nine beaches in this phase, and 24308 follow-up interviews were completed. The overall response rate was 73%. After excluding those respondents who swam in the mid-week before or after the weekend trials, the number of usable responses was 18741, representing 77% of the total. The swimmer and non-swimmer numbers at the nine beaches were 14464 (77%) and 4277 (23%), respectively. This ratio of swimmers to non-swimmers at the subtropical beaches of Hong Kong was very different from those observed in the studies at the temperate coastal beaches of England [24] and freshwater beaches of Canada [21], where the swimmers only represent 13% and 43% the beachgoer populations, respectively.

Swimming habits and demographic information

It was found the beachgoers in Hong Kong on average spent 3·5 h on the nine popular beaches; and the 'swimmers' usually swam in beach water for 1·3 h (the duration of exposure) at weekends.

Amongst the 24308 beachgoers interviewed, a total of 18392 (76%) belonged to family groups. The number of families participating in the study was 5284.

The non-swimming controls differed from swimmers in the distribution of sex; occupation; and the percentage eating barbecue food at the beaches. These factors were however not important in affecting the swimming-associated symptom rates, as the overall rates unadjusted and adjusted for demographic variables were not significantly different.

Microbial beach-water quality

The overall geometric mean densities of the nine microbial indicators at the beaches under study are given in Table 1. The beaches were listed in the order of increasing levels of pollution as indicated by their mean *E. coli* counts. Other microbial indicators (e.g. faecal streptococci and staphylococci) however gave different pictures on the relative degrees of pollution of these beaches. For instance, the mean staphylococci levels of Lido and Clear Water Bay Beaches were higher than those of Old Cafeteria Beach, even though the latter was most seriously polluted in terms of *E. coli* densities.

Relationships between microbial indicators

The relationships between various microbial indicators in beach waters were assessed (see Table 2). There was high correlation amongst the commonly recognized indicators of faecal pollution, namely faecal coliforms, *E. coli*, faecal streptococci and enterococci; but low amongst the various microbial indicators

Table 1. *Overall mean densities of various microbial indicators in water samples collected from nine Hong Kong beaches, 1987*

	Geometric mean density per 100 ml								
Beach	Faecal coliforms	*E. coli*	*Klebsiella* spp.	Faecal streptococci	Enterococci	Staphylococci	*Pseudomonas aeruginosa*	Total fungi	*Candida albicans*
Deep Water	127	69	40	40	31	1181	7	124	4
Shek O	254	119	94	31	28	427	2	275	7
Stanley Main	425	142	214	96	85	295	4	**560**	6
New Cafeteria	402	243	79	43	40	281	6	149	4
Clear Water Bay	**599***	254	**273**	**140**	**156**	**1630**	**9**	**693**	**17**
Lido	574	266	210	**103**	53	**2963**	5	131	**8**
Repulse Bay	488	**269**	105	98	**95**	921	**13**	295	7
Butterfly	**794**	**414**	**239**	75	38	1141	5	28	7
Old Cafeteria	**3166**	**1714**	**943**	**286**	**248**	**1285**	**43**	**763**	**12**
Overall	508 (0·65)†	249 (0·63)	164 (0·83)	81 (0·61)	65 (0·55)	866 (0·57)	7 (0·73)	227 (0·93)	7 (0·75)

* For each indicator, the microbial densities of the three beaches with the highest geometric mean counts are in **bold** type.

† Figures in parentheses are mean log standard deviation of microbial indicator densities at the nine beaches.

Table 2. *Correlation coefficients amongst the densities of various microbial indicators in 667 beach water samples**

	Faecal coliforms	*E. coli*	*Klebsiella* spp.	Faecal streptococci	Enterococci	Staphylococci	*Pseudomonas aeruginosa*	Total fungi	*Candida albicans*
Faecal coliforms	**1·0**†								
E. coli	**0·93**	**1·0**							
Klebsiella spp.	**0·83**	**0·66**	**1·0**						
Faecal streptococci	**0·51**	**0·50**	0·43	**1·0**					
Enterococci	**0·64**	**0·62**	**0·54**	**0·72**	**1·0**				
Staphylococci	0·25	0·26	0·20	0·25	0·31	**1·0**			
Pseudomonas aeruginosa	0·42	0·42	0·31	0·43	**0·52**	0·30	**1·0**		
Total fungi	0·24	0·23	0·21	0·23	0·30	0·12	0·23	**1·0**	
Candida albicans	0·29	0·28	0·27	0·36	0·43	0·25	0·29	0·18	**1·0**

* All correlation coefficient were significant at $P \leqslant 0{\cdot}05$ (*t* test).

† Correlation coefficient $\geqslant 0{\cdot}5$ is in **bold** type.

Table 3. *Perceived symptom rates for swimmers and non-swimmers at nine Hong Kong beaches, 1987*

Beach	Geometric mean per 100 ml		No. of usable responses		Symptoms per 1000 respondents†							
	E. coli	Staphylo-cocci			GI	HCGI	Ear	Eye	Skin	Respir-atory	Fever	Total
Deep Water Bay	69	1181	S‡	1927	4·7	2·1	1·0	7·3	9·9	22·8	9·9	46·2
			NS	499	2·0	2·0	0·0	0·0	6·0	4·0	6·0	14·0
			§		2·7	0·1	1·0	7·3*	3·9	18·8**	3·9	32·2**
Shek O	119	427	S	1939	7·2	3·1	1·0	9·3	10·8	19·6	11·4	54·7
			NS	748	5·4	1·3	0·0	2·7	9·4	14·7	0·0	30·8
			§		1·8	1·8	1·0	6·6*	1·4	4·9	11·4**	23·9**
Stanley Main	142	295	S	1549	10·3	1·3	0·7	5·2	11·0	16·1	7·8	47·1
			NS	595	5·0	0·0	0·0	3·4	3·4	6·7	3·4	16·8
			§		5·3	1·3	0·7	1·8	7·6*	9·4*	4·4	30·3**
New Cafeteria	243	281	S	237	0·0	0·0	0·0	4·2	16·9	16·9	0·0	38·0
			NS	72	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
			§		0·0	0·0	0·0	4·2	16·9	16·9	0·0	38·0*
Clear Water Bay	254	1630	S	2061	2·4	1·0	0·5	3·4	18·4	9·7	7·3	39·3
			NS	389	0·0	0·0	0·0	0·0	7·7	0·0	0·0	7·7
			§		2·4	1·0	0·5	3·4	10·7	9·7*	7·3*	31·6**
Lido	266	2963	S	1800	6·7	1·1	2·2	4·4	25·6	26·1	7·8	66·1
			NS	509	0·0	0·0	0·0	2·0	9·8	0·0	2·0	13·8
			§		6·7*	1·1	2·2	2·4	15·8*	26·1**	5·8	52·3**

Repulse Bay	269	921	S	2472	6·5	3·6	0·8	7·3	9·3	11·0	8·1	38·8
			NS	628	0·0	0·0	0·0	0·0	1·6	6·4	4·8	12·7
			§		6·5*	3·6	0·8	7·3*	7·7*	4·6	3·3	26·1**
Butterfly	414	1141	S	1754	7·4	5·1	0·6	2·9	4·0	14·3	8·6	33·1
			NS	543	0·0	0·0	0·0	0·0	1·8	9·2	1·8	12·9
			§		7·4*	5·1*	0·6	2·9	2·2	5·1*	6·8	20·2**
Old Cafeteria	1714	1285	S	725	2·8	2·8	1·4	1·4	23·5	13·8	6·9	44·1
			NS	294	0·0	0·0	0·0	3·4	6·8	3·4	0·0	13·6
			§		2·8	2·8	1·4	−2·0	16·7*	10·4	6·9	30·5**
Overall	249	866	S	14464	6·0	2·5	1·0	5·5	13·3	16·6	8·4	45·8
			NS	4277	1·9	0·5	0·0	1·4	5·6	6·3	2·3	16·1
			§		4·1**	2·0**	1·0*	4·1**	7·7**	10·3**	6·1**	29·7**
			RR		3·2	5·0	—	3·9	2·4	2·6	3·7	2·8

** $P \leqslant 0{\cdot}01$; * $P \leqslant 0{\cdot}05$ (t test).

† An individual with multiple symptoms may be counted in more than one category.

‡ S, swimmers; NS, non-swimmers.

§ Swimming-associated illness rate (S rate − NS rate).

RR, Relative risk (S rate/NS rate).

—, Indeterminate because of no cases among non-swimmers.

which may come from both faecal and non-faecal sources, such as staphylococci, *Pseudomonas aeruginosa*, total fungi and *Candida albicans*. The correlation between these two categories of indicator organisms (for instance, between *E. coli* and staphylococci) was low.

An analysis of the *E. coli* to faecal coliforms ratios for the 667 samples revealed, on average, *E. coli* only represented 57% of the faecal coliform group in the beach waters of Hong Kong. The significance of this low percentage in subtropical waters is discussed in a separate paper [29]. The mean enterococci to faecal streptococci ratio for these beach-water samples was 144%, indicating the counts obtained using the KF medium were generally lower than those obtained with the m-Enterococcus medium in analysing Hong Kong beach waters.

Symptomatic illness rates

The perceived symptom rates obtained for the nine beaches are presented in Table 3. The rates for most of the symptom groups were generally higher for swimmers than non-swimmers. For individual symptom categories, the overall perceived illness rates for swimmers were significantly higher than those for the non-swimming control group. The HCGI symptom rate for swimmers was 5 times higher than that for non-swimmers; for eye or fever symptoms rate, 4 times; and for GI, skin, respiratory or total illness rate, 2–3 times. There was also a significant excess of total illness for swimmers than non-swimmers at each of the nine beaches.

Apart from Old Cafeteria Beach, which is mainly polluted by livestock wastes, significant swimming-associated GI symptom rates were observed for the more polluted beaches (Lido, Repulse Bay and Butterfly), as indicated by their overall geometric mean *E. coli* counts.

The beachgoers did not report on symptoms suggestive of serious disease such as shigellosis or enteric fever.

Onset and duration of symptoms

The incubation periods and duration of the perceived symptoms amongst the beachgoers are presented in Table 4. The HCGI symptoms (or gastroenteritis) developed among swimmers were characterized by their short incubation periods, with a median of only 2 days. The duration of the HCGI symptoms was around 2 days. As for the skin rash symptoms, they were usually developed after 1 day, and lasted for 4 days amongst the bathers.

Age distribution of symptoms

The swimming-associated symptom rates for different age groups are presented in Fig. 2. The swimming-associated GI, HCGI, skin, respiratory, fever and total illness symptoms were more prevalent among children under 10 years of age than older bathers (see Table 5).

Risks at 'relatively unpolluted' and 'barely acceptable' beaches

To see whether swimming in more polluted waters poses higher health risks than in less polluted ones, the beaches under study were grouped into two categories, 'relatively unpolluted' (RU) and 'barely acceptable' (BA). This grouping was undertaken for each of the microbial indicators. The threshold level of an indicator

Table 4. *Incubation periods and duration of perceived symptoms in days, Hong Kong study 1987*

Symptoms	Swimmer			Non-swimmer		
	Number reporting	Median incubation period	Average duration	Number reporting	Median incubation period	Average duration
Gastrointestinal						
HCGI	23	2	2·3	2	4	4·5
Overall	78	1	1·9	6	< 1	3·2
Ear and eye						
Ear	13	2	1·5	0	—	—
Eye	66	1	2·9	5	1	3·2
Skin rash	176	1	4·0	26	1	5·2
Respiratory	228	2	3·5	25	2	4·2
Fever	116	2	4·2	10	2	3·8

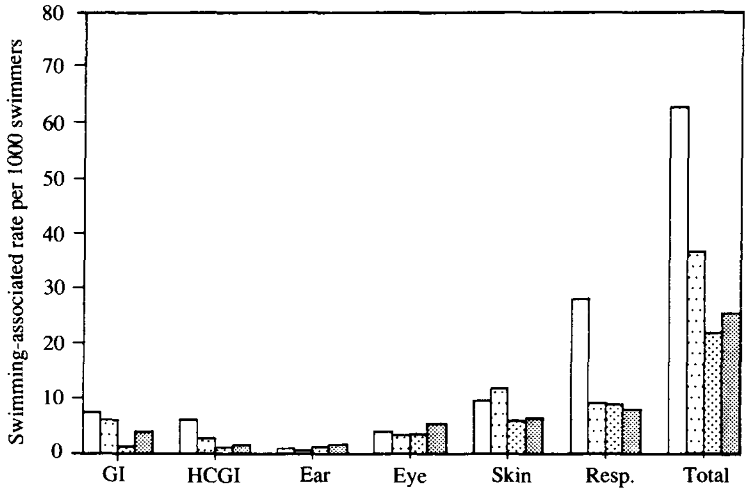

Fig. 2. Swimming-associated symptom rates for different age groups at nine Hong Kong beaches, 1987. □, 0–4 years; ⊡, 5–10; ▨, 11–25; ▩, > 25.

for differentiating RU from BA beaches is the lowest density with the greatest number of symptom groups showing significant difference in the swimming-associated illness rates for the two categories of beaches (see Table 6 for the determination of the thresholds for *E. coli* and staphylococci). It is the microbial density beyond which the risks of swimming-related diseases are expected to increase significantly. A geometric mean *E. coli* density of 180 per 100 ml was found to be the threshold for differentiating BA from RU beaches, with the former showing a significant excess of swimming-associated GI, HCGI, skin and total illness symptom rates than the latter. The threshold level for staphylococci was a geometric mean density of 1000 per 100 ml. BA beaches with mean staphylococci densities higher than this limit exhibited significantly higher swimming-associated illness rates for skin, respiratory and total illness when compared with RU beaches.

The swimming-associated symptom rates at BA and RU beaches are presented

Table 5. *Relationship between age and swimming-associated symptom rates for nine Hong Kong beaches, 1987*

		No. of usable responses	Symptoms per 1000 respondents†							
			GI	HCGI	Ear	Eye	Skin	Respiratory	Fever	Total
Children < 10 years	S‡	3668	7·1	4·1	0·3	3·8	16·9	23·2	21·5	62·4
	NS	1149	0·0	0·0	0·0	0·0	5·2	7·8	5·2	16·5
	§¶		7·1**	4·1*	0·3	3·8*	11·7**	15·4**	16·3**	45·9**
⩾ 10 years of age	S	10796	5·7	1·9	1·2	6·1	11·9	14·4	3·0	40·1
	NS	3128	2·6	0·6	0·0	1·9	6·1	5·8	1·3	16·3
	§		3·1	1·3	1·2	4·2**	5·8**	8·6**	2·5*	23·8**

** $P \leqslant 0{\cdot}01$; * $P \leqslant 0{\cdot}05$ (*t* test).

† An individual with multiple symptoms may be counted in more than one category.

‡ S, swimmers; NS, non-swimmers.

§ Swimming-associated illness rate (S rate − NS rate).

¶ The swimming-associated GI, HCGI, skin, respiratory, fever and total illness symptom rates were significantly higher for children under 10 than for older bathers at $P \leqslant 0{\cdot}05$ (*t* test).

Table 6. *Determining the threshold* E. coli *and staphylococci levels for differentiating 'relatively unpolluted' (RU) and 'barely acceptable' (BA) beaches*

(*a*) *E. coli*

RU/BA†	Dividing line *E. coli*/100 ml	GI	HCGI	Skin	HCGI and skin	Respiratory	Total illness
1/8	90‡	n	*	*	*	n	n
2/7	130	*	n	n	*	n	n
3/6	180	*	*	*	*	n	*
4/5	250	*	*	*	*	n	n
5/4	260	*	*	*	*	n	n
6/3	270	*	*	n	n	n	n
7/2	340	*	*	n	*	n	*
8/1	840	n	n	*	*	n	n

(*b*) Staphylococci

RU/BA†	Dividing line Staph/100 ml	GI	HCGI	Skin	HCGI and skin	Respiratory	Total illness
1/8	300‡	n	n	n	n	n	n
2/7	350	n	n	n	n	n	n
3/6	650	*	n	*	n	*	n
4/5	1000	n	n	*	*	*	*
5/4	1150	n	n	*	*	*	*
6/3	1250	n	n	*	*	*	*
7/2	1450	n	n	*	*	*	*
8/1	2200	n	n	*	*	*	*

* Significant difference between the swimming-associated symptom rates for RU and BA beaches at $P \leqslant 0{\cdot}05$ (*t* test).

n, No significant difference between the swimming-associated symptom rates for RU and BA beaches at $P \leqslant 0{\cdot}05$ (*t* test).

† Number of RU or BA beaches.

‡ Midway between the highest geometric mean microbial count of the RU beaches and the lowest count of the BA beaches.

in Table 7. It is apparent the following perceived symptom groups – GI, HCGI, skin, respiratory and total illness – were pollution-related, as significantly higher rates of these symptoms were observed at BA beaches than at RU beaches.

Relationships between microbial indicator densities and swimming-associated health risks

The relationships between swimming-associated symptom rates and geometric mean densities of various microbial indicators in beach waters over the whole phase of study were analysed (see Table 8). The mean *E. coli* densities were correlated with swimming-associated HCGI ($r = 0{\cdot}51$) or skin ($r = 0{\cdot}55$) symptom rates. The highest correlation ($r = 0{\cdot}73$) was however found between *E. coli* and combined swimming-associated HCGI and skin symptom rates. Faecal coliforms, faecal streptococci and enterococci showed lower correlation with HCGI or skin symptom rates when compared with *E. coli*. On the other hand, the geometric mean staphylococci levels were significantly correlated with swimming-associated ear or sore throat symptom rates. When compared with other microbial indicators,

Table 7. *Swimming-associated symptom rates at 'barely acceptable' (BA) and 'relatively unpolluted' (RU) beaches, Hong Kong 1987*

	Geometric mean per 100 ml		Symptoms per 1000 respondents						
			GI	HCGI	Ear	Eye	Skin	Respir-atory	Total
Faecal coliforms	411–3200	BA (6)†	5·1	2·5	0·9	3·1	9·4	10·1	31·1
	0–410‡	RU (3)	1·8	0·9	0·9	6·5	3·1	11·1	27·0
		§	3·3***	1·6**	0·0	−3·4	6·3***	−1·0	4·1*
E. coli	181–1800	BA (6)	5·3	2·6	0·9	3·5	10·0	10·5	31·8
	0–180	RU (3)	2·8	1·1	0·9	5·2	4·0	10·5	27·8
		§	2·5**	1·5**	0·0	−1·7	6·0***	0·0	4·0*
Klebsiella spp.	101–1000	BA (6)	5·1	2·5	0·9	3·1	9·4	10·1	31·1
	0–100	RU (3)	1·8	0·9	0·9	6·5	3·1	11·1	27·0
		§	3·3***	1·6**	0·0	−3·4	6·3***	−1·0	4·1*
Faecal streptococci	56–290	BA (6)	5·1	2·5	0·9	3·1	9·4	10·1	31·1
	0–55	RU (3)	1·8	0·9	0·9	6·5	3·1	11·1	27·0
		§	3·3***	1·6**	0·0	−3·4	6·3***	−1·0	4·1*
Enterococci	40–250	BA (6)	4·5	1·9	1·0	3·2	11·2	11·4	33·5
	0–39	RU (3)	3·6	2·2	0·8	5·4	2·2	8·9	24·3
		§	0·9	−0·3	0·2	−2·2	9·0***	2·5	9·2***
Staphylococci	1001–3000	BA (5)	4·5	1·8	1·0	3·3	9·1	14·0	33·3
	0–1000	RU (4)	3·9	2·2	0·8	5·3	5·5	5·8	25·7
		§	0·6	−0·4	0·2	−2·0	3·6***	8·2***	7·6***
Pseudomonas aeruginosa	6–45	BA (5)	3·7	1·7	0·8	4·9	8·8	10·4	29·7
	0–5	RU (4)	4·8	2·2	1·1	3·4	6·6	10·8	30·9
		§	−1·1	−0·5	−0·3	1·5	2·2	−0·4	−1·2
Total fungi	141–770	BA (6)	3·3	1·9	0·7	4·0	7·9	6·4	26·6
	0–140	RU (3)	5·5	2·0	1·2	4·2	7·3	16·6	35·0
		§	−2·2	−0·1	−0·5	−0·2	0·6	−10·2	−8·4
Candida albicans	7–20	BA (6)	4·4	2·4	1·0	4·0	8·0	8·7	29·1
	0–6	RU (3)	3·3	0·7	0·8	4·4	6·5	14·5	31·5
		§	1·1	1·7**	0·2	−0·4	1·5	−5·8	−2·4

*** Swimming-associated illness rate for BA beaches significantly higher than for RU beaches at $P \leqslant 0{\cdot}01$; ** at $P \leqslant 0{\cdot}05$; and * at $P \leqslant 0{\cdot}06$ (t test).

† Figures in parentheses are numbers of BA or RU beaches.

‡ Midway between the highest geometric mean microbial count of the RU beaches and the lowest count of the BA beaches.

§ Difference in illness rates between BA and RU beaches.

Table 8. *Correlation coefficients for swimming-associated symptom rates against geometric mean densities of various microbial indicators at nine Hong Kong beaches, 1987*

	Faecal coliforms	*E. coli*	*Klebsiella* spp.	Faecal streptococci	Enterococci	Staphylococci	*Pseudomonas aeruginosa*	Total fungi	*Candida albicans*
Gastrointestional (GI)									
HCGI	0·49	0·51*	0·42	0·32	0·17	0·19	0·21	−0·32	0·28
Overall	0·18	0·13	0·23	0·30	0·04	0·43	−0·02	−0·37	0·11
Ear and Eye									
Ear	0·21	0·18	0·30	0·32	0·11	0·66**	0·13	0·04	0·24
Eye	−0·86	−0·78	−0·91	−0·77	−0·64	−0·18	−0·49	−0·29	−0·49
Overall	−0·82	−0·75	−0·86	−0·72	−0·63	−0·04	−0·49	−0·29	−0·44
Skin	0·53*	0·55*	0·44	0·54*	0·53*	0·18	0·54*	0·36	0·23
Respiratory									
Sore throat	−0·35	−0·37	−0·26	0·00	−0·09	0·56*	−0·05	0·05	−0·06
Heavy cold	−0·03	0·01	−0·08	−0·05	−0·17	0·23	0·03	−0·15	−0·26
Overall	−0·18	−0·16	−0·18	−0·06	−0·18	0·36	−0·02	−0·16	−0·26
HCGI and skin	0·71***	0·73***	0·58**	0·65**	0·60**	0·24	0·62**	0·29	0·32
Others									
Headache	0·21	0·09	0·31	0·18	0·38	0·23	0·04	0·40	0·42
Fever	0·15	0·07	0·33	0·06	0·02	0·24	−0·22	0·14	0·55*
Total illness	−0·01	−0·02	0·00	0·12	0·02	0·36	0·01	0·05	−0·05

*** Statistically significant at $P \leqslant 2\%$; ** at $P \leqslant 5\%$; and * at $P \leqslant 6\%$ (*t* test).

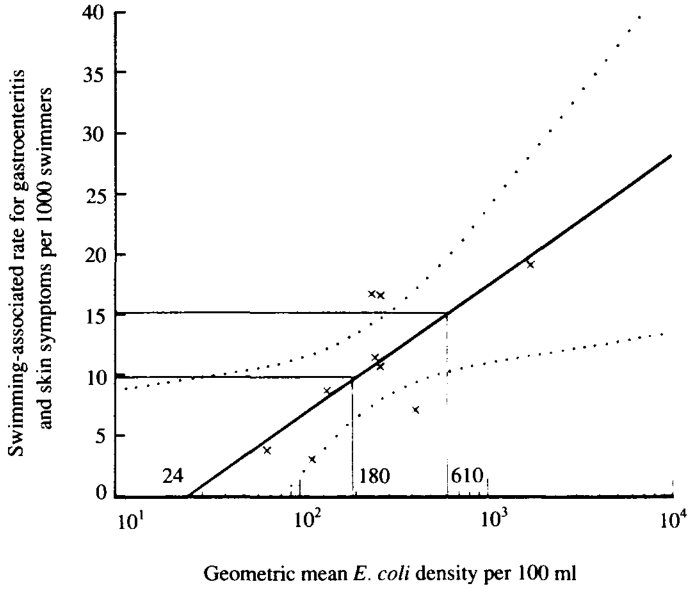

Fig. 3. Linear relationships between swimming-associated gastroenteritis and skin symptom rates and geometric mean *E. coli* densities at nine Hong Kong beaches. The line of best fit was calculated by the method of least squares. ——, Regression line; ....., 95% confidence interval.

staphylococci showed the highest correlation with total illness; and were the only indicator having a positive correlation with respiratory symptom rates.

A linear relationship could be established between geometric mean *E. coli* densities and combined swimming-associated HCGI and skin symptom rates for individual beaches (see Fig. 3). The regression equation was $Y = 10{\cdot}8 \log X - 14{\cdot}89$ ($P \leqslant 0{\cdot}05$), where X was the mean *E. coli* density over the whole study period and Y the symptom rate.

No significant equation relating *E. coli* to HCGI or skin symptom rates: or staphylococci to ear or sore throat symptom rates was found.

DISCUSSION

The present study shows swimmers at the coastal beaches of Hong Kong are more likely to complain of GI, HCGI, ear, eye, skin, respiratory and total illness than non-swimmers; and swimming in the more polluted beach waters carries a significantly higher risk of contracting GI, HCGI, skin, respiratory and total illness than in cleaner ones. These findings clearly contradict a conclusion of the Committee on Bathing Beach Contamination of PHLS [4], that 'bathing in sewage-polluted seawater carries only a negligible risk to health, even on beaches that are aesthetically very unsatisfactory'.

Indeed, the study suggests illness associated with swimming is a public health problem in Hong Kong. The swimmers in Hong Kong are exposed to a higher risk of developing HCGI symptoms than non-swimmers by 5 times; and for GI, eye, skin and total illness, 2–4 times. Even with the low symptom rates, the large number of bathers at Hong Kong beaches means the total incidences of various perceived symptoms are very high. For Repulse Bay, the most popular beach, it has been estimated in one bathing season, 14000 people suffer from GI symptoms and 58000 suffer from some form of illness. Over the whole beach-going population, no fewer than 400000 illness incidences attributable to swimming occur each year.

The swimming-associated symptom rates obtained in the Hong Kong study, being the first of its kind in Asia, have been compared with those of similar studies at USA, Egypt, Canada, Israel and England [16, 17, 20–24]. For beaches with similar degrees of faecal pollution (as reflected by *E. coli* or enterococci densities), the gastrointestinal symptom rates for Hong Kong beaches (4·1 per 1000 swimmers on average) are generally lower than those reported for the marine beaches of Israel, England and USA. The rates for Hong Kong beaches are more akin to those obtained for the local bathers at Alexandria beaches. The skin symptom rates for the marine beaches of Egypt, England and USA are higher than those for Hong Kong beaches. The total illness rates for the Canadian and Hong Kong beaches are similar, namely in the range of 20–30 per 1000 swimmers.

The incubation periods and duration of gastrointestinal symptoms amongst the swimmers in Hong Kong are similar to those observed for the bathers at US beaches [16, 38]. This may suggest swimming-associated gastroenteritis in Hong Kong and USA is caused by similar aetiologic agents. Cabelli [16, 38] has suggested they are viral in nature, being Norwalk virus and rotavirus originating from human sewage. He has also postulated the higher gastrointestinal illness rates obtained in the US study than in the Egyptian study could be attributed to the disparities in the immune state of the populations to these aetiologic agents. The lower incidence of swimming-associated GI symptoms for local bathers than for visitors from Cairo at Alexandria beaches would also be due to the higher level of immunity developed in Alexandria residents to infection by such viruses. It may be possible that the low incidence of GI symptoms amongst the swimmers in Hong Kong is due to the immunity developed in the local population to enteric viruses, because of repeated exposure through various faecal–oral routes since very early age.

Children below 10 years of age were found to have significantly higher symptom rates of GI, HCGI, skin, respiratory, fever and total illness than older bathers in Hong Kong. This suggests the levels of immunity to the infectious agents causing swimming-associated illness are different between infants and the rest of the swimmer population. Studies at USA, Egypt and Israel have also shown a similar phenomenon, in respect of gastrointestinal symptoms [16, 23, 38].

The present study indicates *E. coli* is the best indicator of the health risks associated with swimming in Hong Kong beaches. This bacterial species showed the highest correlation with combined swimming-associated gastroenteritis and skin symptom rates when compared with other faecal indicators, namely faecal coliforms, enterococci and faecal streptococci.

A quantitative relationship between *E. coli* and the combined symptom rates has also been established, for setting health-related beach-water quality standards. This together with those indicator–illness relationships reported by overseas workers are summarized in Table 9. Cabelli [39] has suggested the enterococci level in marine bathing water is the best single measure of its quality in relation to the risk of infectious disease. Table 9 however reveals *E. coli* is a better indicator in terms of correlation with swimming-associated health risks, for the coastal beaches of Hong Kong and Egypt. Whilst enterococci are the best indicator for the US marine beaches, this is obviously not a universal phenomenon.

An important point Table 9 also helps to illustrate is that it may not be appropriate for a country to adopt the microbial beach water quality standards developed by other countries, particularly if they were far away geographically. The immune state of the populations to the aetiologic agents of swimming-associated disease is probably different, and so are the indicator–illness relationships. It is important individual countries should conduct their own epidemiological studies, so that health-related bathing-water quality standards which suit their particular conditions could be developed.

The Hong Kong study is the first one which has grouped the swimming-associated symptom rates for HCGI and skin together, and studied their degree of association with microbial indicator densities. This grouping is justified because firstly, the HCGI symptom group (or acute gastroenteritis) by itself already consists of a multiple of symptoms, including gastrointestinal illness and fever. Secondly, there were reports of enterovirus (in particular coxsackievirus) infections amongst bathers, and the syndromes of these viral infections include among others, gastroenteritis, respiratory, fever, rashes, and hand-foot-and-mouth disease [40]. The strong correlation between *E. coli* and combined skin and gastroenteritis symptom rates may suggest enteroviruses, in addition to Norwalk virus and rotavirus as suggested by Cabelli [16, 38], are possible aetiologic agents of swimming-associated illness; and *E. coli* is a good indicator of such viral infections among bathers.

The present study points to the need of using more than one microbial indicator for defining bathing water quality adequately and setting health-related standards in Hong Kong. This secondary indicator should not be another faecal indicator such as faecal streptococci or enterococci which relates only to gastroenteritis and skin symptoms, but less well than *E. coli* in this regard. It should be associated with other swimming-associated symptoms. The obvious choice is staphylococci, which showed the best correlation with ear, respiratory and total illness when compared with other microbial indicators. This indicator is to complement, but not to replace *E. coli*, as it cannot be used for predicting swimming-associated illness rates amongst the bathers in Hong Kong. The adoption of both *E. coli* and staphylococci as indicators of water pollution is also justified in that they are poorly correlated with each other, and may give different pictures on the level of microbial pollution of the same beach (see Tables 1–2).

Geometric mean densities of 180 *E. coli* per 100 ml and 1000 staphylococci per 100 ml are the thresholds for differentiating 'barely acceptable' from 'relatively unpolluted' beaches – in respect of swimming-associated GI, HCGI and skin symptom rates for *E. coli*; and skin, respiratory and total illness rates for staphylococci. These thresholds are recommended for adoption as new microbial water quality objectives for the bathing beaches of Hong Kong. They should become guidelines for designing future wastewater treatment and disposal facilities at or near bathing beaches.

Table 9. *Regression relationships between geometric mean microbial indicator densities and swimming-associated health risks for setting beach water quality standards*

	HK beaches	US beaches*			Egypt beaches*			
		Marine	Freshwater		Cairo visitors		Alexandria residents	
Indicator	*E. coli*	Entero-cocci	Entero-cocci	*E. coli*	Entero-cocci	*E. coli*	Entero-cocci	*E. coli*
Slope	0·0922†	0·0456	0·0589	0·0687	0·0378	0·0454	0·0842	0·1143
Intercept	1·382	0·677	0·938	1·464	2·073	1·784	1·935	1·352
Correlation coefficient	0·73	0·75	0·74	0·80	0·88	0·89	0·68	0·76
Risk level‡	15	19‖	8	8	19	19	19	19
Corresponding indicator density§	610	35	26	103	620	443	3400	3340

* For studies at US and Egypt, see refs [16] and [20].

† For comparison purposes, the subject of the regression line (Y on X) in Fig. 3 was changed.

‡ Swimming-associated symptoms per 1000 swimmers. The rates are of HCGI and skin symptoms for Hong Kong; HCGI for US; and GI for Egypt.

§ Seasonal geometric mean bacterial count per 100 ml.

‖ Nineteen cases per 1000 person was the rate accepted by the US EPA [18]; used only as an example.

Table 10. *Classification of Hong Kong beaches based on swimming-associated health risk levels*

Rank	Swimming-associated gastroenteritis and skin symptom rate (per 1000 swimmers)	Seasonal geometric mean *E. coli* density (per 100 ml)
Good	0	24
Acceptable	10	180
Barely acceptable	15	610
Unacceptable	> 15	> 610

The proposed bacterial water quality objective of a geometric mean *E. coli* density of 180 per 100 ml corresponds to a combined swimming-associated HCGI and skin symptom rate of 10 per 1000 bathers (see Fig. 3). A geometric mean *E. coli* density of 610 per 100 ml (equivalent to 60% compliance with the 1000 *E. coli* per 100 ml criterion), which has already been adopted as the dividing line between 'barely acceptable' and 'unacceptable' beaches in Hong Kong, corresponds to a swimming-associated HCGI and skin symptom rate of 15 per 1000 bathers. This represents the maximum acceptable risk of illness connected with swimming in Hong Kong beaches, unknowingly adopted by the Hong Kong community. On the other hand, those beaches with a geometric *E. coli* density of 24 per 100 ml or less, where the swimming-associated HCGI and skin illness symptoms would be undetectable, can be regarded as having 'good' water quality.

Based on the above observations, a new annual four-tier ranking system has been developed for the coastal beaches of Hong Kong (see Table 10). Rather than just designating the beaches as 'acceptable' or 'unacceptable', they are classified into 'good', 'acceptable', 'barely acceptable' and 'unacceptable'. The public are presented with the information so that they can make the choice themselves as to which beach they should go for swimming, after taking into account the health risk levels involved. It is notable the acceptable risk criterion for the beaches of Hong Kong is 15 gastroenteritis and skin symptoms per 1000 swimmers, whilst the criterion recommended by US EPA [18] for the coastal beaches of USA is 19 gastroenteritis symptoms per 1000 swimmers.

This system for ranking beaches according to health risk levels associated with swimming was first used in Hong Kong in late 1988 [41], and accepted by the municipal councils, the beach management authorities. The number of bathing beaches with water quality classified as 'good' was 9; 'acceptable', 19; 'barely acceptable', 7; and 'unacceptable', 7 in that year.

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