ORIGINAL ARTICLE

# Distribution and determinants of trihalomethane concentrations in indoor swimming pools

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**Objectives:** For many decades chlorination has been used as a major disinfectant process for public drinking and swimming pool water in many countries. However, there has been rising concern over the possible link between disinfectant byproducts (DBPs) and adverse reproductive outcomes. The purpose of this study was to estimate the concentrations of trihalomethanes (THMs) in some indoor swimming pools in London and their variation within and between pools and any correlation with other factors.
**Methods:** Water samples were collected from eight different indoor swimming pools in London. A total of 44 pool samples were collected and analysed for total organic content (TOC) and THMs. Water and air temperature were measured along with the pH during the collection of pool samples. The level of turbulence and the number of people in the pool at the time were also assessed.
**Results:** The geometric mean concentration for all swimming pools of TOC was 5.8 mg/l, of total THMs (TTHMs) 132.4 μg/l, and for chloroform 113.3 μg/l. There was a clear positive linear correlation between the number of people in the swimming pool and concentrations of TTHMs and chloroform ($r$=0.7, p<0.01), and a good correlation between concentrations of TOC and TTHMs ($r$=0.5, p<0.05) and water temperature and concentrations of TTHMs ($r$=0.5, p<0.01). There was a larger variation in THMs within pools than between pools.
**Conclusion:** Relatively high concentrations of THMs were found in London's indoor swimming pools. The levels correlated with the number of people in the pool, water temperature, and TOC. The variation in concentrations of THMs was greater within pools than between pools.

Chlorination is a process whereby harmful pathogens are eliminated from the water. During this process, not only unwanted micro-organisms are removed but several organic halogenated compounds known as chlorination disinfection byproducts (DBPs) are formed at the same time.[1] Excessive exposure to DBPs may be harmful to humans.[2]

Trihalomethanes (THMs), generally the most common DBPs, are volatile halogenated hydrocarbons, which can vaporise from water into the atmosphere. When chlorine is added to the water, it reacts with the organic matter in the water such as skin scales and residuals from body care products to form various DBPs, including THMs.[1 3] The THMs include chloroform ($CHCl_3$), bromodichloromethane (BDCM)($CHCl_2Br$), chlorodibromomethane (CDBM) ($CHClBr_2$), and bromoform ($CHBr_3$). In general, chloroform is the most common occurring THM. The International Agency for Research on Cancer has classified chloroform as a 2B carcinogen.

Adverse reproductive outcomes such as spontaneous abortion, birthweight, neural tube defects, urinary tract defects, and others have been associated with exposure to THMs, but the evidence so far seems to be inconsistent and inconclusive.[4]

There are three different exposure routes—ingestion, inhalation, and dermal absorption—and all routes can contribute to the total uptake of THMs.[1 5] Everyday pathways include drinking tap water, showering, bathing, washing up, and boiling water. For swimmers, the greatest uptake is likely to be through dermal absorption because a large surface area of skin is exposed and inhalation from the air above the pool water surface.[1] The rate of inhalation depends on the intensity of the exercise.

Weisel and Shepard[6] measured mean chloroform concentrations of 85 μg/l in the water and 87 μg/m³ in air in swimming pools. Lindstrom *et al*[7] reported chloroform concentrations of 68 and 73 μg/l in the water. Matthiessen and Jentsch[8] measured mean concentrations of THMs of 29.7 μg/l in water and 142 μg/m³ in air in swimming pools in Germany. Slightly lower concentrations were measured in both air and water by Camman and Hubner[9] in Germany. They also measured CDBM, BDCM, and bromoform, but the concentrations of these were much lower than chloroform with a maximum of 6.51 μg/l of CDBM in water and 22.4 μg/m³ for BDCM in air. In Holland, Aiking *et al*[10] measured concentrations of chloroform in water of 18.4 μg/l in indoor pools and 24.0 μg/l in outdoor pools. Aggazzotti *et al*[11–14] conducted a series of studies in Modena, Italy, and found correlations between chloroform concentrations in air and water and the number of swimmers,[11 13] and chloroform concentration in water and free and combined chlorine residual and water pH,[11] but these were generally only weak to moderate correlations.

At present there are few publications on the amount of total organic content (TOC) and concentrations of THMs in United Kingdom swimming pools. Therefore, this study aims to provide a greater understanding of the concentrations of THMs in United Kingdom indoor swimming pools, the variability in these concentrations, and any correlation with other factors.

## METHODS

### Sampling

A list of indoor swimming pools in London was obtained from Sportline, a sports telephone information service. A total of 29 swimming pools were identified and eight were chosen to take part in this project. The indoor swimming pools were primarily chosen for convenience of travelling to collect samples.[15]

**Abbreviations:** DBPs, disinfectant byproducts; THMs, trihalomethanes; TTHMs, total THMs; TOC, total organic content; $CHCl_3$, chloroform; BDCM ($CHCl_2Br$), bromodichloromethane, CDBM ($CHClBr_2$), chlorodibromomethane; $CHBr_3$, bromoform

**Table 1** Coefficient of variation for the methods and analysis of TOC and trihalomethanes

| Variables | Coefficient of variation (%) |
|---|---|
| TOC | 13.4 |
| Chloroform | 3.9 |
| BDCM | 4.2 |
| CDBM | 2.0 |
| TTHM | 3.3 |

**Table 3** Within and between pool variance components (%) of trihalomethanes and TOC in eight United Kingdom swimming pools

| Variables | $Q_w$ | $Q_w$ (%) | $Q_b$ | $Q_b$ (%) |
|---|---|---|---|---|
| TOC | 2.3 | 31 | 5.0 | 69 |
| Chloroform | 1581.9 | 77 | 467.6 | 23 |
| BDCM | 34.2 | 96 | 1.4 | 4 |
| CDBM | 4.2 | 93 | 0.3 | 7 |
| TTHM | 0.1 | 79 | 0.027 | 21 |

$Q_b$, between pool variance; $Q_w$, within pool variance; %, percentage of total variance.

The swimming pool water sampling was conducted between 19 June 2000 and 14 July 2000. For each pool at least one sample was collected once every week for 3 consecutive weeks. In some pools two samples were collected at the same time to estimate the coefficient of variation. Pool samples were collected in 150 ml brown bottles for analysis of both THMs and TOC. The bottles were filled to the top and the caps were tightly sealed with a screw cap to prevent THMs volatising into the environment. Samples were refrigerated and stored until the end of the week when they were sent to the Thames Water Quality Centre, a United Kingdom Accredited Scheme laboratory in Reading, to be analysed. Also, a few samples of tap water were taken for comparison.

Water and air temperature, pH, turbulence, and the number of people in the pool were recorded when the samples were collected.

### Laboratory analysis

The method of TOC analysis was based on that described in the instrumental measurement of total organic carbon, total oxygen demand, and related factors.[16] An O.I. model 700 Carbon analyser was used to analyse the concentration of TOC. Samples were firstly treated with phosphoric acid, then by nitrogen to convert organic carbon to carbon dioxide. The samples were then treated with a sodium persulphate solution at 100°C, then by nitrogen to convert any organic carbon left to carbon dioxide. The carbon dioxide was trapped and concentrated on an absorbent where it was heated rapidly, and measurements were taken with an infrared detector. This process took about 10 minutes a sample. The detection limit for TOC was 0.1 mg/l.

The THMs analysis was based on the method described for chloro- and bromo-trihalomethanated methane in water[17] and halogenated solvents and haloforms in water using a static headspace technique.[18] This method can detect chloroform, bromoform, CDBM, BDCM, trichloroethene, trichloroethane (1,1,1), and carbon tetrachloride. The samples were individually sealed in a vial fitted with a crimp on septum cap. The samples were equilibrated at 70°C for 27 minutes in a Perkin Elmer HS 101 headspace analyser. A subportion of the headspace gas was then transferred through a needle (100°C) and transfer line (120°C) to a Perkin Elmer 8500 gas chromatograph fitted with a capillary column (HP5 25 m×0.32 mm or equivalent). Oven temperature started at 40°C and ramped up at 25°C/minute to 163°C after 5.5 minutes isothermal time. Detection took place with an ECD detector (300°C). The injector temperature was 150°C.

The samples had to be in equilibrium before processing. The distribution of a liquid is directly proportional to the distribution of its vapour. The samples were individually sealed in a vial fitted with a crimp on septum cap. The vial was left in an oven for a fixed time for headspace gas equilibrium with the sample. The vial was then punctured and samples were transferred onto a capillary gas chromatograph, where the components were then separated and measured. Full quality control procedures were in place. The detection limit for each of chloroform, bromoform, BDCM, CDBM, and trichloroethene was 2.5 μg/l, for trichloroethane (1,1,1) and tetrachloroethene 1.0 μg/l, and for carbon tetrachloride 0.3 μg/l. Concentrations of trichloroethene, trichloroethane (1,1,1), and carbon tetrachloride were all below the limit of detection and are not further described in this paper.

The coefficient of variation of the method was calculated (table 1). The coefficients of variation (%) were low. Most were below 5% variability but TOC showed a 13.4% coefficient of variation.

### Statistical analysis

The analyses were carried out using statistical software SPSS. Spearman rank correlation was used to estimate the correlation between the various variables. A one way analysis of variance (ANOVA) model was used to estimate the swimming pool variance components.

## RESULTS

### Concentrations

A summary of the swimming pool concentrations is shown in table 2. The arithmetic mean (AM) of TOC concentration of the swimming pools was 6.3 mg/l, compared with 2.3 mg/l in tap water in London. The AM of chloroform was 121.1 μg/l in

**Table 2** Characteristics of trihalomethanes and other factors in United Kingdom swimming pools

| | Samples (n) | Arithmetric mean | Geometric Mean | Geometric SD | Minimum | Maximum |
|---|---|---|---|---|---|---|
| Chloroform (μg/l) | 24 | 121.1 | 113.3 | 1.5 | 45 | 212 |
| BDCM (μg/l) | 24 | 8.3 | 6.9 | 1.8 | 2.5 | 23 |
| CDBM (μg/l) | 24 | 2.7 | 2.0 | 2.3 | 0.67 | 7 |
| Bromoform (μg/l) | 24 | 0.9 | 0.8 | 1.5 | 0.67 | 2 |
| TTHM (μg/l) | 24 | 132.4 | 125.2 | 1.4 | 57 | 222.5 |
| TOC (mg/l) | 24 | 6.3 | 5.8 | 1.5 | 3.3 | 12.9 |
| Air temperature (°C) | 24 | 26.9 | 26.8 | 1.1 | 22.3 | 34 |
| Water temperature (°C) | 24 | 31.1 | 31.0 | 1.1 | 27.5 | 34.5 |
| pH | 24 | 7.4 | 7.4 | 1.0 | 7 | 8.13 |
| People (n) | 24 | 7.1 | 5.9 | 1.9 | 1 | 16 |

**Table 4** Spearman correlation coefficients of trihalomethanes and other factors in United Kingdom swimming pools (n=24)

| Variables | Spearman correlation coefficient | p Value |
|---|---|---|
| TOC *v* chloroform | 0.5 | <0.05 |
| TOC *v* bromoform | –0.2 | – |
| TOC *v* air temperature | 0.4 | – |
| TOC *v* water temperature | 0.4 | – |
| TOC *v* pH level | –0.2 | – |
| TOC *v* No. of people | 0.5 | p<0.05 |
| TOC *v* TTHM | 0.5 | p<0.05 |
| Chloroform *v* BDCM | –0.2 | – |
| Chloroform *v* CDBM | –0.3 | – |
| Chloroform *v* air temperature | 0.3 | – |
| Chloroform *v* water temperature | 0.4 | p<0.05 |
| Chloroform *v* pH | –0.1 | – |
| Chloroform *v* number of people | 0.7 | p<0.01 |
| Chloroform *v* TTHM | 1.0 | p<0.01 |
| Bromoform *v* CDBM | 0.5 | p<0.05 |
| Bromoform *v* BDCM | 0.1 | – |
| Bromoform *v* TTHM | –0.4 | p<0.05 |
| BDCM *v* CDBM | 0.9 | p<0.01 |
| TTHM *v* air temperature | 0.4 | – |
| TTHM *v* water temperature | 0.5 | p<0.01 |
| TTHM *v* pH | –0.1 | – |
| TTHM *v* number of people | 0.7 | p<0.01 |

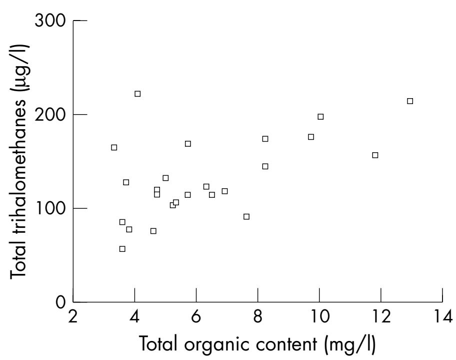


**Figure 1** A plot of concentrations of TTHMs and TOC.

the swimming pools and 3.5 µg/l in tap water. Similar BDCM concentrations were found in swimming pools and tap water samples; 8.3 µg/l and 7.5 µg/l, respectively.

## Variance within and between swimming pools

The variances within and between swimming pool components were estimated and concentrations of chloroform, BDCM, CDBM, and TTHMs were found to have a much greater variation within pools than between pools whereas TOC had a greater variation between pools (table 3).

## Correlation

Correlation coefficients are shown in table 4. The concentrations of TOC and TTHMs showed a good correlation; where TOC increased, TTHMs increased ($r=0.5$, $p<0.05$, fig 1). A positive linear correlation was found between water temperature and the TTHMs ($r=0.5$, $p<0.01$, fig 2). The strongest correlation was found for the number of people in the swimming pools and concentrations of TTHMs and chloroform ($r=0.7$, $p<0.01$, fig 3).

# DISCUSSION

The main findings of this study were: (*a*) that there are relatively high concentrations of TTHMs in indoor swimming pools in London, (*b*) that the variation in concentrations of

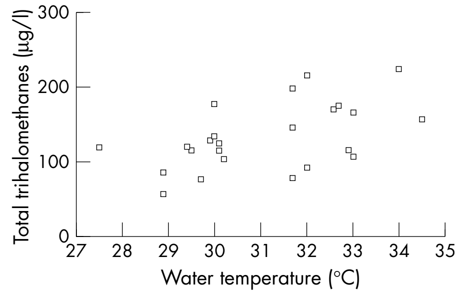


**Figure 2** A plot of concentrations of TTHMs and water temperature.

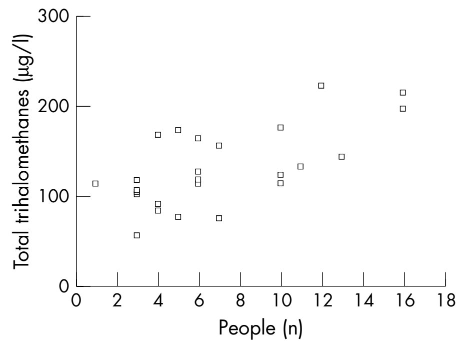


**Figure 3** A plot of concentrations of TTHMs and the number of people in the swimming pools.

TOC was greater between pools whereas for chloroform, BDCM, and CDBM variation was greater within pools, (*c*) that there were strong correlations between concentrations of TTHMs and chloroform, TOC, water temperature, and the number of people in the swimming pools.

## Concentration of TTHMs

The concentrations of chloroform collected in these swimming pools were found to be relatively high compared with other studies conducted outside the United Kingdom. In Italy, Aggazzotti *et al*[11–14] found concentrations of 17–47 µg/l of chloroform in the water and 66–653 µg/m$^3$ of chloroform in the air. For non-competitive swimmers, a mean of 0.4 µg/l chloroform was found in the blood between 1 and 40 minutes after exposure. Weisel and Shepard[6] measured mean chloroform concentrations of 85 µg/l in the water and 87 µg/m$^3$ in air in swimming pools, but other studies[7 9 10] found much lower concentrations in their swimming pool studies. The concentrations of TTHMs in London swimming pools were also considerably higher than the concentrations in tap water.

## Individual THMs: variation within and between pools

Although other studies generally focused on one swimming pool we included several pools and estimated the variance components within and between pools. The analyses showed that most variance in TOC was between swimming pools. This is probably because TOC is affected by few factors—such as the number of people in the swimming pool. Chloroform, BDCM, CDBM, and TTHMs concentrations varied more within the swimming pools. These concentrations depend on a more complex set of factors—such as the amount of TOC in the water, pH, temperature, and number of people.

## Correlation

Concentrations of TOC and chloroform were correlated and this is not surprising as when chlorine is added to water, it reacts with some components of TOC to form chloroform. Concentrations of TOC in tap water were almost three times lower than those in swimming pools, and this suggests that the greatest proportion of the TOC originated in the pool possibly from the swimmers. Concentrations of TOC should be reduced as far as is reasonably practicable to reduce the formation of THMs.

Concentrations of TTHMs were also correlated with the temperature of swimming pool water. As water temperature rose, more chloroform was formed, especially in indoor swimming pools, in which water and air temperature are generally higher than in outdoor swimming pools, and therefore more TTHMs are likely to be formed in both water and air.

The number of people in the swimming pool was positively correlated with the concentrations of TTHMs and chloroform. Also Aggazzotti *et al*[14] found that the number of people in the swimming pools affected the concentration of TTHMs. In one study they found that 40–50 competitive swimmers in the pool doubled the concentration of TTHMs in air and water compared with a pool without swimmers. The TTHMs and chloroform concentrations in the water increased probably because as there were more swimmers in the pool, the turbulence and splashes increased and more organic material was released, which allowed TTHMs to form.

### Uptake of THMs

In this study we only measured the THMs concentrations in water, but some other studies have measured the actual uptake, which was consiberable. Levesque *et al*[19] measured the body burden (based upon 11 male swimmers) resulting from exposure to chloroform in water and air of an indoor swimming pool. A 1 hour swim was postulated to result in a chloroform dose of 65 μg/kg/day, 141 times the dose from a 10 minute shower (0.46 μg/kg/day)[19] and 93 times greater than exposure by ingestion of tap water as demonstrated by Jo *et al*.[20] Lindstrom *et al*[7] estimated that the dermal route of exposure accounted for 80% of the blood chloroform concentration during swimming. Aggazotti *et al* (11) found a correlation between chloroform concentrations in plasma and number of swimmers ($r_s$=0.32), time spent swimming ($r_s$=0.57), chloroform concentrations in water ($r_s$=0.48), and chloroform concentrations in environmental air ($r_s$=0.74), whereas 4.7% of the variance in plasma concentrations was explained by the intensity of physical activity. Aggazotti *et al*[14] reported a mean chloroform uptake of 25.8 μg/h (range 22–28 μg/h) at rest and 176.8 μg/h (134–209 μg/h) after 1 hour swimming (arithmetic mean of chloroform concentration in pool water was 33.7 μg/l). Lower concentrations of uptake were reported for CDBM and BDCM. Also other studies,[6 8–10] recorded considerable uptake of chloroform during swimming. Potential uptake for people swimming in the pools in this study is likely to be higher than reported in other studies as the concentration of THMs in water were higher. However, it is important to note that inhalation is an important route of exposure and the uptake through this route is affected by various factors including for example, the number of swimmers, turbulence, and breathing rate. As we did not take any measurements in air it is difficult to estimate the actual uptake in our population.

### Implications of risk to health

Most of the reproductive health studies of DBPs have been carried out focusing on drinking water. Swimming seems to have a greater risk of exposure to DBPs as uptake may occur through three different routes; inhalation, dermal absorption, and, to a certain extent, ingestion and the amount of TTHMs concentration seems to be higher compared with drinking water. Therefore it is essential to gain a better understanding of the possible determinants of TTHMs in swimming pools and this pathway should be included in epidemiological studies where possible. Of course it is important to remember that a major determinant of the total uptake is likely to be the frequency and duration of swimming and more information should be collected on this to allow the estimation of any potential health risks.

### Messages

- Trihalomethane concentrations in swimming pools were relatively high compared with tap water.
- Trihalomethane concentrations correlated with the total organic content, the number of people in the water, and the temperature of the water.
- Trihalomethane concentrations varied considerably within pools from day to day.

### Policy implications

- Swimming pools could be a major pathway for the uptake of trihalomethanes among pregnant women who go swimming often.
- Further work should be carried out to assess the importance of these relatively high concentrations of trihalomethanes on potential health risks.
- Trihalomethane concentrations should be reduced as far as possible in swimming pools while maintaining effective control against waterborne microbiological disease.

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