

## Factors Influencing Formation of Trihalomethanes in Swimming Pool Water

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Swimming pool waters are subjected to various treatment processes like aeration sedimentation, filtration and disinfection. The dosing of swimming pool water with chlorine based chemicals is the most common and versatile technique currently in use for disinfection. The use of chlorine as disinfectant in water leads to formation of chlorinated halohydrocarbons (Glaze et al. 1979). The chemical kinetics favours the formation of trihalomethanes (THMs) ; which results on reaction of chlorine (or bromine or iodine) with organic precursors present in water. The formation of THMs has been of the greatest concern since last three decades as these compounds have been linked to cancer in laboratory animals (Tardiff 1977). The formation of THMs have been reported to occur in swimming pool water due to the interaction of chlorine with organic matter present in it (Beech et al. 1980; Lahl et al 1981 ; Weil et al. 1980 ; Eichelsdorfer et al. 1980). The various sources responsible for the contamination of swimming pool water include the contact with the skin and the urine of users. Batjer et al. (1980) have estimated that even under strict hygienic conditions each bather contributes several grams of organic material to the water per bathing period, thus promoting the synthesis of THMs.

The danger in swimming pools contaminated with THMs is not from ingestion, but from absorption of THMs through the skin. Since THMs are volatile, inhalation is also another route of exposure. Several studies have measured the increase in THMs levels in blood plasma following swimming in THMs-contaminated water (Beech et al. 1980). Though EPA has currently set a limit on total THMs in drinking water of 100 ppb, THM concentration in swimming pool may exceed several times the EPA limit. The formation of THMs in pool water is of great public health concern. It has been proposed to identify and characterize the factors that influence the THMs formation in swimming pools and are discussed in the paper.

## MATERIALS AND METHODS

Water samples were collected in 125 ml glass bottles with no head-space and quenched with ascorbic acid for the available residual chlorine. One set of samples was collected from swimming pools before chlorination and another, after one hour of chlorination. The swimming pools located in Nagpur city were monitored during the months of April and May in 2001 in summer season when the ambient temperature was found in the range of 102-117° F. The numbers of swimmers are also being reported more in the summer season. One of the swimming pool (SP-1), with most strict hygienic conditions and well maintained was selected for regular monitoring and taken as a model pool for comparison purposes. Samples were monitored thrice a week from this pool for a period of 2 months in this season. Samples were preserved immediately after collection and brought to the laboratory and analysed within 3 hours after collection. The instantaneous THMs (InstTHMs) concentrations present in the water at the moment of sampling have been measured for chloroform, bromodichloromethane (BDCM), dibromochloromethane (DBCM) and bromoform.

Samples for InstTHMs and general water quality parameters were analysed as per approved standard methods (APHA, AWWA and WEF, 1998). Liquid-liquid extraction method followed by qualitative and quantitative estimation by gas chromatograph with electron capture detector (GC-ECD) has been used for determination of individual species of THMs. The quality assurance / quality control (QA / QC) in the form of percentage recovery, standard deviation and relative standard deviation of the method were established for all the four THMs at the concentrations of 150 and 200  $\mu\text{gL}^{-1}$  (Table 1).

**Table 1.** Quality assurance and quality control data for THMs.

Parameter	THMs Conc. ( $\mu\text{gL}^{-1}$ )	Chloroform	CDBM	BDCM	Bromoform
Relative Standard Deviation	200	2.93	0.15	0.23	1.11
	150	0.30	0.52	0.42	0.5
Standard Deviation	200	0.90	0.05	0.05	0.33
	150	0.20	0.74	0.54	0.74
Recovery (%)	200	98	96	84	97
	150	98.5	95.7	84	97.3

## RESULTS AND DISCUSSION

The THMs levels and general water quality of pool SP-1 and other pools of the city have been compared. The highest total THMs (TTHMs) in SP-1 has been found as 175.23  $\mu\text{gL}^{-1}$  after chlorination, recorded in April 4<sup>th</sup> week. In other pools the TTHMs concentration have been found high and the maximum

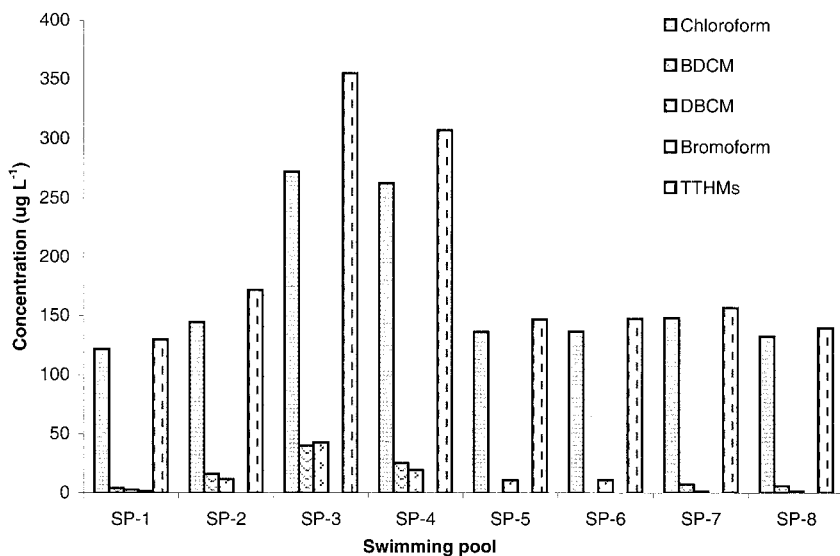
concentration has been reported as  $354.82 \mu\text{gL}^{-1}$  (Fig. 1). In May 1<sup>st</sup> week, the variation in TTHMs concentration in pool SP-1 have been found lowest (Fig. 2) and associated to low TOC and residual chlorine levels (Table 2 and Fig. 3a & b). The laboratory experiments in pool SP-1 samples showed that there is an increase in THMs after chlorination (Fig 2) and the same has also been observed in other pools. The concentration of THMs after chlorination have been found higher than unchlorinated samples, but much variation has not been observed. A 10-12% increase in THMs concentration have been recorded. Among THMs the chloroform levels have been found in significant concentrations followed by BDCM and DBCM in low  $\mu\text{gL}^{-1}$ . Excepting in few samples, the bromoform has not been found in any of the samples collected prior to and after chlorination.

The highest TTHMs level in post chlorinated samples have been found at the end of 3<sup>rd</sup> and first few days of 4<sup>th</sup> week of April as  $175.23 \mu\text{gL}^{-1}$  recorded during the high TOC of  $16 \text{mgL}^{-1}$  and lowest  $93.8 \mu\text{gL}^{-1}$  with TOC of  $10 \text{mgL}^{-1}$  in the mid of May 1<sup>st</sup> week (Fig 3a & b). The fulvic acid content in the pool waters did not exceed  $0.5 \text{mgL}^{-1}$  which indicates that fulvic acid must be largely excluded in playing a significant role as organic precursors. The main source of organic matter found in swimming pool water may be the urine and other human biological products such as sweat, human grease and cosmetics. The increase in THMs formation in pools is due to the increase in number of persons coming for swimming and seems to be responsible for increase in organic matter, and also the turbulence factor while swimming. The increase in THMs formation has been found to be associated with the increase in residual chlorine. The residual chlorine increased in April in 1<sup>st</sup> and 4<sup>th</sup> week ( $0.5$  and  $0.6 \text{mgL}^{-1}$  respectively) and resulted into more THMs formation ( $153.03$  and  $175.23 \mu\text{gL}^{-1}$ ) (Table 2). It may be due to the availability of more hypochlorous acid to react with the organic matter present in pool. Thus there should be an optimum chlorine dosing for disinfection of swimming pools.

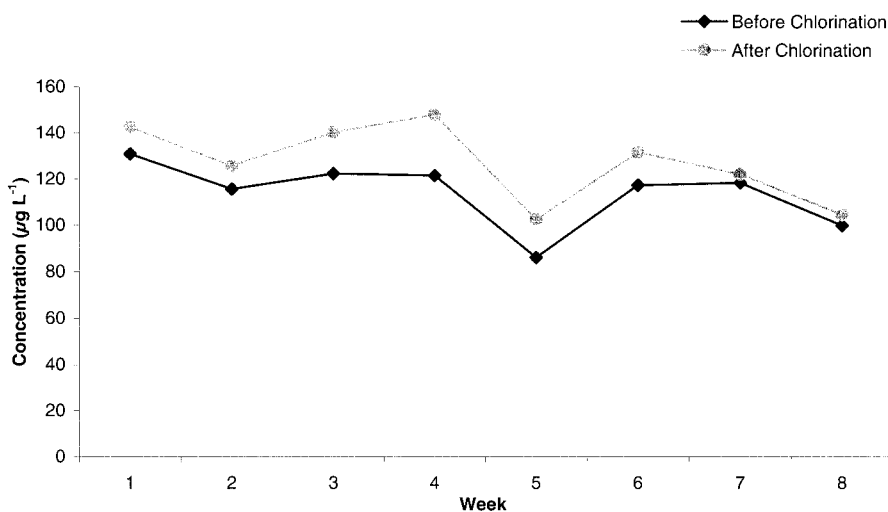
The variation in temperature influence the THMs formation. The increase in ambient temperature favours the evaporation of VOC's which are highly volatile and tend to escape easily in the atmosphere. The THMs formation have been found lowest in May 4<sup>th</sup> week, ( $90.03 \mu\text{gL}^{-1}$  before and  $94.785 \mu\text{gL}^{-1}$  after chlorination) when the ambient ( $47^\circ\text{C}$ ) and pool water ( $30\text{-}32^\circ\text{C}$ ) temperatures (Fig. 2 and Table 2) were recorded highest.

The high pH enhances the formation of hypochlorite ions which favours haloform reaction thus making the conditions favourable for the THMs. There has not been found much pH variation (Table 2) in the pool water, hence no correlation between pH and THMs formation could be established in the present study (Fig. 4a & b).

Among the pools monitored the pool SP-3 showed the highest THMs formation  $354.82 \mu\text{gL}^{-1}$  (Fig. 1). THMs levels in other pools have also been found higher than pool SP-1, chloroform levels have been found higher than other THMs. The



**Figure 1.** Total THMs concentration in swimming pools of Nagpur city.



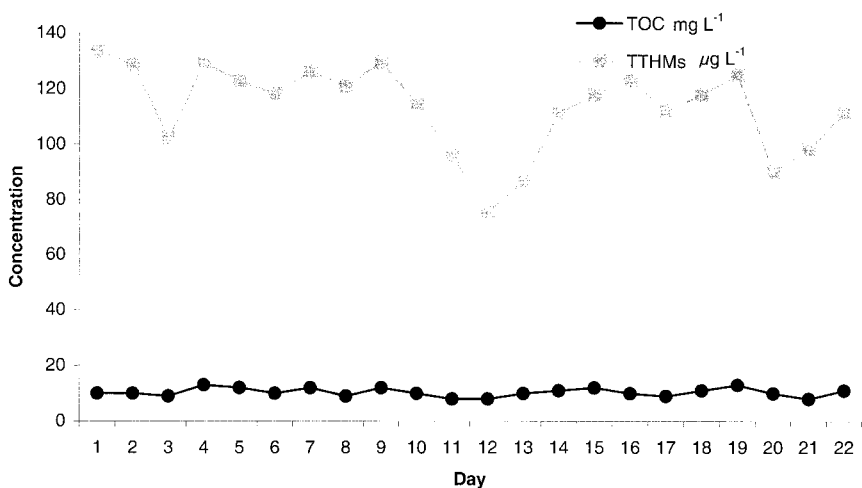
**Figure 2.** Average weekly variation in total THMs concentration in swimming pool water SP-1.

**Table 2.** Swimming pool SP-1 water quality in summer.

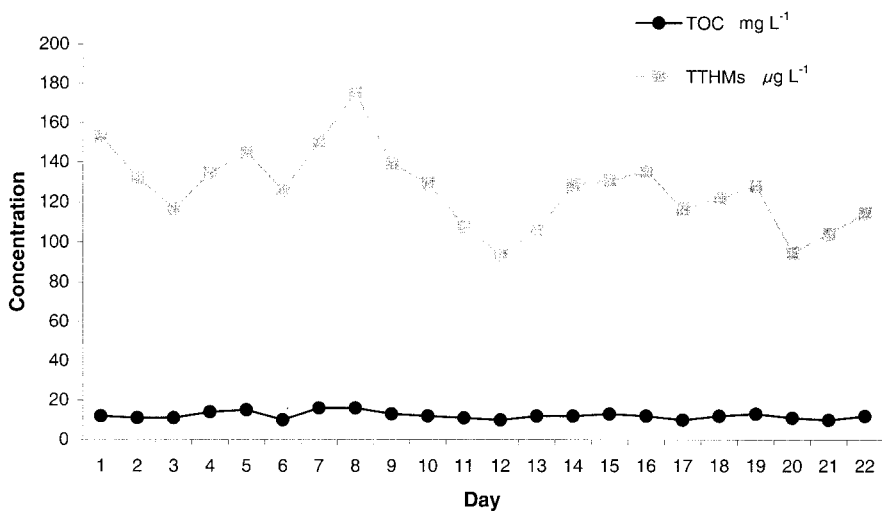
Month - Week	Day	pH		Conductivity (ms cm <sup>-1</sup> )		Turbidity (NTU)		Temperature (°C)		TOC (mg L <sup>-1</sup> )		Residual Chlorine (mg L <sup>-1</sup> )	
		B. Cl*	A. Cl**	B. Cl	A. Cl	B. Cl	A. Cl	B. Cl	A. Cl	B. Cl	A. Cl	B. Cl	A. Cl
April – I	Monday	8.3	8.1	327	360	1.0	1.5	28	29	10	12	0.2	0.5
	Thursday	8.2	7.8	320	354	1.5	1.5	28	29	10	11	0.2	0.4
April – II	Monday	8.3	8.4	350	380	1.5	1.0	29	30	9	11	>0.1	0.2
	Thursday	8.4	8.4	385	390	1.5	1.5	28	30	13	14	0.3	0.4
April – III	Monday	8.3	8.4	390	410	1.0	1.5	29	31	12	15	0.3	0.5
	Wednesday	8.4	8.3	405	414	1.0	1.5	30	31	10	10	>0.1	0.2
	Friday	7.3	7.3	430	434	1.5	1.5	30	31	12	16	0.2	0.5
	Monday	8.4	8.4	450	460	1.5	1.5	28	29	9	16	0.3	0.6
April – IV	Wednesday	8.4	8.5	470	470	1.0	1.5	28	30	12	13	0.2	0.4
	Friday	8.1	8.2	475	475	1.0	1.0	30	31	10	12	0.1	0.3
	Monday	8.3	8.0	430	460	1.5	2.5	30	30	8	11	>0.1	0.1
	Wednesday	8.3	8.2	470	488	1.5	1.5	29	30	8	10	>0.1	0.2
May – I	Friday	8.1	8.3	440	490	1.0	1.5	30	31	10	12	0.1	0.3
	Monday	7.6	7.7	480	490	1.0	1.5	30	32	11	12	0.2	0.4
May – II	Wednesday	7.9	8.0	470	473	1.0	1.5	29	30	12	13	0.2	0.3
	Friday	8.2	8.2	473	500	1.5	1.5	30	31	10	12	0.1	0.4
May – III	Monday	8.0	8.4	510	520	1.0	1.5	30	33	9	10	0.3	0.4
	Wednesday	8.2	8.5	500	510	1.0	1.5	29	32	11	12	0.2	0.4
	Friday	8.1	8.4	530	540	1.5	1.5	30	33	13	13	0.2	0.4
	Monday	7.2	7.9	400	440	1.5	2.0	29	31	10	11	0.1	0.1
May – IV	Wednesday	8.4	8.3	450	470	1.0	1.5	30	32	8	10	0.2	0.3
	Friday	8.4	8.7	430	485	1.0	1.5	30	32	11	12	0.2	0.3

\* B. Cl - Before Chlorination

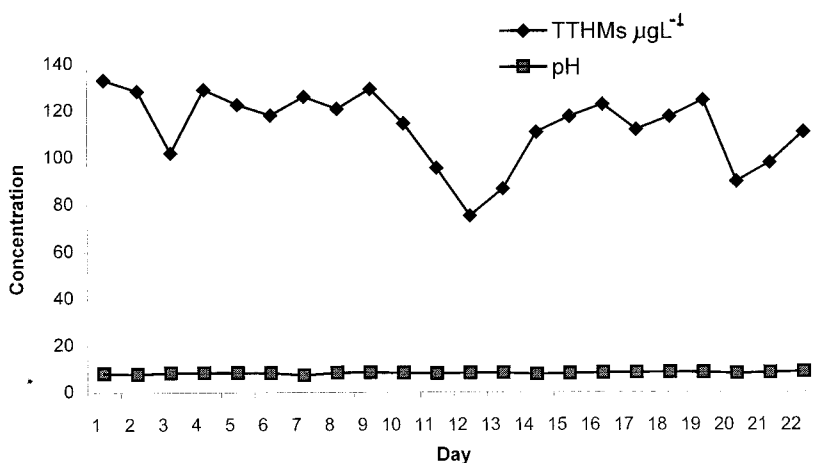
\*\* A. Cl - After Chlorination



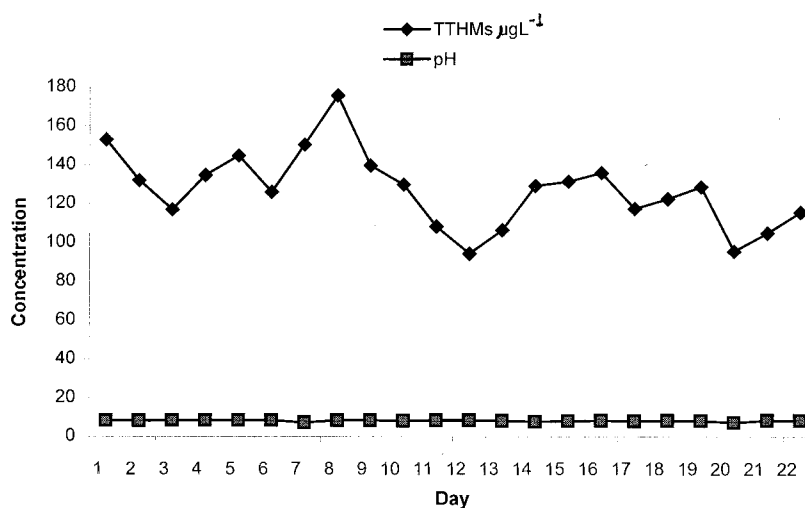
**Figure 3(a).** Variation in TTHMs with respect to TOC in swimming pool water SP-1 (unchlorinated).



**Figure 3(b).** Variation in TTHMs with respect to TOC in swimming pool water SP-1 (chlorinated).



**Figure 4(a).** Variation in TTHMs with respect to pH in swimming pool water SP-1 (unchlorinated).



**Figure 4(b).** Variation in TTHMs with respect to pH in swimming pool water SP-1 (chlorinated).

water quality of pool SP-1 has been found most safe and contain limited levels of TTHMs in comparison to others (Fig. 1).

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