Chlorinated and Nonchlorinated-Volatile Organic Compounds (VOCs) in Drinking Water of Peninsular Malaysia
(Sebatian Organik Meruap Terklorin dan Tidak Terklorin (VOCs) dalam Air Minum Semenanjung Malaysia)

MD. PAUZI ABDULLAH* & SOH SHIAU CHIAN

ABSTRACT

A survey undertaken in Peninsular Malaysia has shown that volatile organic compounds (VOCs), both chlorinated and non-chlorinated, are present in selected drinking water samples. In this study, analyses of VOCs were performed by means of solid phase microextraction (SPME) with a 100 µm polydimethylsiloxane (PDMS) fibre followed by gas chromatography - mass spectrometry detector (GC-MSD). Samples from different points of the distribution system networks were taken and analysed for 54 VOCs of different chemical families. The results of the study indicated that chloroform constituted the major portion of the VOCs in all samples analysed. In addition to trihalomethanes (THMs), other abundant compounds detected were cis *and* trans-1,2-dichloroethylene, trichloroethylene, 1,2-dibromoethane, benzene, toluene, ethylbenzene, chlorobenzene, 1,4-dichlorobenzene and 1,2-dichlorobenzene. However, the measured concentrations did not exceed the National Guideline for Drinking Water Quality 2000 in any case. No clear relationship between the status of development of a state in Malaysia to the levels and types of VOCs detected in its drinking water was noted. Nevertheless, the finding of anthropogenic chemicals, even at low concentrations, gave credibility to the viewpoint that improper development and disposal practices threatened the purity of the drinking water.*

Keywords: Drinking water; solid phase microextraction; volatile organic compound

ABSTRAK

Satu tinjauan yang dilakukan di Semenanjung Malaysia telah menunjukkan kehadiran kedua-dua sebatian organik meruap (VOCs) yang terklorin atau yang tidak terklorin di dalam air minum terpilih. Dalam kajian ini VOCs telah dianalisis melalui teknik pengekstrakan mikro fasa pepejal (SPME) menggunakan gentian polidimetil siloksana (PDMS) 100 µm dan diikuti oleh analisis dengan kromatografi gas – spektometer jisim (GC-MSD). Sampel dari pelbagai titik di sepanjang sistem agihan diambil dan dianalisis kehadiran 54 jenis VOCs daripada pelbagai kumpulan. Hasil analisis menunjukkan bahawa kloroform merupakan bahagian utama dalam VOCs pada semua sampel yang dianalisis. Selain daripada trihalometana (THMs), sebatian lain yang banyak dikesan ialah sis *dan* trans-1,2-dikloroetilena, trikloroetilena, 1,2-dibromoetana, benzena, toluena, etilbenzena,klorobenzena, 1,4-diklorobenzena dan 1,2-diklorobenzena. Walau bagaimanapun, aras semua sebatian tersebut masih tidak melangkaui Garis Panduan Kualiti Air Minum Kebangsaan 2000. Tidak terdapat hubungan yang jelas di antara status pembangunan sesuatu negeri di Malaysia dengan kehadiran sesuatu sebatian VOCs dalam air minum. Sungguhpun demikian penemuan kehadiran sebatian antropogenik di dalam sumber air minum jelas menunjukkan bahawa amalan yang tidak baik dalam penggunaan dan pelupusan bahan kimia akan mengancam ketulenan sumber air minum.*

Kata kunci: Air minum; pengekstrakan mikro fasa pepejal; sebatian organik meruap

INTRODUCTION

Volatile organic compounds (VOCs) are considered important environmental contaminants because many are mobile, persistent and toxic, even at very low concentrations. The environment consists of a complex system of interacting media, and VOCs do not necessarily remain in the medium where they originate (Squillace et al. 1999). In certain media, many VOCs can have a short half-life of a few hours due to degradation, whereas in other media they can be persistent and show little degradation over a period of years.

VOCs are contained in many manufactured products, including paints, adhesives, gasoline and plastics. There are also other anthropogenic sources of VOCs, such as emissions and evaporation from mobile sources, like automobiles, or commercial activities that are not involved in manufacturing, such as refuelling stations and dry-cleaning operations (Squillace et al. 2002).

In addition to anthropogenic emission, VOCs can be gained or lost during the water treatment and distribution process. Because chlorine is generally used as a disinfectant in municipal water supply systems in Malaysia (Sukiman

& Md. Pauzi 1993), trihalomethanes (THMs) are formed during chlorination at the treatment plant or in the distribution system (Md. Pauzi et al. 2002), whereas some VOC concentrations decrease during the water treatment process, such as during aeration (Golfinopoulos et al. 1998; Faust & Aly 1998).

The purpose of this paper is to provide a current assessment of the occurrence and state of VOCs in drinking water supplies in Peninsular Malaysia.

MATERIALS AND METHODS

REAGENTS AND STANDARDS

The pure standard solution of a VOC mixture used in this study was purchased from TCI, Tokyo Kasei Kogyo Co. Internal standard used was fluorobenzene (FB), and the surrogate standard used was 4-bromofluorobenzene (BFB), both purchased from Supelco, USA. The deionised water used for preparing standard solutions was purified by an Arium 611 DI system from Sartorius AG.

CALIBRATION

Intermediate calibration standard solutions (200 mg/L) were prepared by diluting 1.0 mL of stock standard (2000 mg/L) to 10 mL in a volumetric flask with methanol. A series of working standard solutions (10 – 100 μg/L) were prepared appropriately in 50 mL volumetric flasks using deionised water. These were used for the quantitative analysis of VOC components. The internal and surrogate standard solutions (200 mg/L) were prepared in the same manner as the calibration standard solutions.

SAMPLING

Water sampling was performed on a monthly basis for 12 months (June 2003 to June 2004) at water treatment plants throughout all 11 states and Federal Territories in Peninsular Malaysia. The sampling points for the analysis included treatment plant outlets (TPO), service reservoir outlets (SRO) and auxiliary outlet points (AOP) at the water pipelines within the distribution systems.

ANALYTICAL METHODOLOGY

Samples were allowed to warm to room temperature (20°C). Approximately 40 mL of sample was then poured into a 50 mL volumetric flask, followed by 20 μL of internal calibration standard, fluorobenzene (FB) and surrogate standard (4-bromofluorobenzene (BFB)) at 200 mg/L. The flask was then filled to the 50 mL mark. The sample was transferred to a 40 mL glass vial with a magnetic stirrer inside and capped with a hole cap and a Teflon-faced silicone rubber septum.

The solid phase microextraction (SPME) device, purchased from Supelco America (Bellefonte, PA) with approximately 7.5 cm of fibre (coated with 100 μm thick stationary phase of polydimethylsiloxane) attached to a 15 cm stainless steel needle was inserted inside the plunger of a Hamilton syringe (Model, 7005). The SPME fibre was previously conditioned according to the manufacturer's recommendations (280°C for 30 min in a GC injector). The fibre was then immersed into the sample for 5 min at ambient temperature with stirring. A 5 min absorption time was the optimum time to extract all VOCs in the water sample.

After this sampling time, the SPME fibre was drawn into the needle and removed from the sample matrix. The fibre was then immediately inserted into the heated gas chromatography (GC) injection port. A desorption time of 10 min was allowed for the analytes to be desorbed from the fibre and introduced into the GC column. Even though desorption is virtually complete in a few seconds for non-polar volatile compounds, desorption should be continued for a few minutes to ensure that no carryover occurs when a blank is inserted after a sample (Wercinski 1999). A fused-silica capillary column CP SIL 8CB (30 m × 0.25 mm, d_f = 0.25 μm; Varian, Inc.) was used on a HP 5890 GC system equipped with a mass spectrometry detector (MSD). The oven temperature program started from 35°C held for 4 min, then increased to 160°C at 6°C/min, and then held at 160°C for 5 min. The total run time was 30 min and the injector temperature was set to 220°C. The MSD acquisition was performed in scan mode from 35 to 260 amu. and in-time scheduled selected ion monitoring mode. The data were acquired with an HP Chemstation equipped with a Wiley 257 mass spectral library which was used to compare the experimental spectra obtained.

54 VOCs are listed with their CAS registry number, method detection limit (MDL), recovery (REC), relative standard deviation (RSD), calibration equation and its respective R^2 (Table 1). The MDLs for the SPME-GC-MSD method were between 0.005 and 1.121 μg/L. The RSD was in the range of 5-12%, which is well within the limit of ±15% (AOAC 1993). The recovery was between 83% and 109%, which is also within the required ±20% accuracy.

RESULTS AND DISCUSSION

The data sets were characterised under three classes (alkanes, alkenes and aromatics). Because there were 54 target compounds, many of them were at or below the detection limit. Therefore, individual compound analyses should focus on the most abundant compounds. Tables 2, 3 and 4 list the 12 most abundant compounds with their respective concentrations and detection rates in all the states in Peninsular Malaysia.

VOCs detected in disinfected waters were mainly trihalomethanes (THMs). Specifically, the results of the analyses revealed that chloroform was detected in all drinking water samples. THMs can be traced to chlorination, as can other by-products of chlorination, such as choralhydrate, dichloroacetic acid, formaldehyde,

TABLE 1. Compounds studied classified into the groups of alkenes, alkanes and aromatics, with their respective validation parameters for targeted VOCs

Groups	VOCs	CAS No.	MDL	REC	RSD	Calibration equation	R^2
Alkenes	1,1-Dichloroethylene	75-35-4	0.925	90	8	$y = 0.196\chi - 0.026$	0.999
	trans-1,2-Dichloroethylene	156-60-5	1.069	103	10	$y = 0.148\chi - 0.013$	0.999
	cis-1,2-Dichloroethylene	156-35-4	0.712	100	8	$y = 0.135\chi - 0.007$	0.998
	1,1-Dichloropropene	563-58-6	0.089	109	12	$y = 0.879\chi - 0.137$	0.998
	cis-1,3-Dichloropropene	10061-01-5	0.482	85	8	$y = 0.694\chi - 0.064$	0.997
	trans-1,3-Dichloropropene	10061-02-6	0.015	96	7	$y = 5.33\chi - 0.248$	0.999
	Trichloroethylene	79-01-6	0.195	91	8	$y = 0.808\chi - 0.045$	0.999
	Tetrachloroethylene	127-18-4	0.101	86	8	$y = 2.71\chi - 0.214$	0.998
	Hexachlorobutadiene	87-68-3	0.029	83	6	$y = 2.60\chi + 0.096$	0.996
Alkanes	Chloroform	67-66-3	0.210	95	11	$y = 0.694\chi - 0.029$	0.998
	Dichlorobromomethane	75-27-4	0.779	85	9	$y = 0.143\chi - 0.001$	0.997
	Dibromochloromethane	124-48-1	0.456	96	7	$y = 0.459\chi - 0.030$	0.997
	Bromoform	75-25-2	0.298	85	9	$y = 0.351\chi - 0.012$	0.997
	Bromochloromethane	74-97-5	0.210	88	11	$y = 0.694\chi - 0.029$	0.998
	Dibromomethane	74-95-3	0.195	91	8	$y = 0.808\chi - 0.045$	0.999
	Methylene chloride	75-09-2	1.121	92	9	$y = 0.027\chi + 0.001$	0.999
	Carbon tetrachloride	56-23-5	0.015	90	10	$y = 1.08\chi - 0.147$	0.998
	1,1-Dichloroethane	75-34-3	0.999	91	8	$y = 0.133\chi - 0.017$	0.997
	1,2-Dichloroethane	107-06-2	0.015	102	10	$y = 1.08\chi - 0.147$	0.998
	1,2-Dibromoethane	106-93-4	0.896	88	9	$y = 0.343\chi - 0.049$	0.997
	1,1,1-Trichloroethane	71-55-6	0.150	85	11	$y = 0.835\chi - 0.099$	0.998
	1,1,2-Trichloroethane	79-00-5	0.897	85	7	$y = 1.19\chi - 0.223$	0.995
	1,1,1,2-Tetrachloroethane	630-20-6	0.188	86	8	$y = 1.93\chi - 0.277$	0.996
	1,1,2,2-Tetrachloroethane	79-34-5	0.187	84	7	$y = 1.10\chi - 0.075$	0.998
	1,2-Dichloropropane	78-87-5	0.195	91	8	$y = 0.808\chi - 0.045$	0.999
	1,3-Dichloropropane	142-28-9	0.594	89	7	$y = 0.701\chi - 0.118$	0.997
	2,2-Dichloropropane	594-20-7	0.210	98	11	$y = 0.694\chi - 0.029$	0.998
	1,2,3-Trichloropropane	96-18-4	0.096	82	6	$y = 1.03\chi - 0.077$	0.995
	1,2-Dibromo-3-chloropropane	96-12-8	0.106	89	9	$y = 8.54\chi + 0.019$	0.995
Aromatics	Benzene	71-43-2	0.015	90	10	$y = 1.08\chi - 0.147$	0.998
	Toluene	108-88-3	0.015	96	7	$y = 5.33\chi - 0.248$	0.999
	Styrene	100-42-5	0.052	85	6	$y = 5.30\chi + 0.258$	0.995
	Ethylbenzene	100-41-4	0.012	85	8	$y = 1.20\chi - 0.027$	0.996
	1,3-Xylene	108-38-3	0.009	92	6	$y = 19.2\chi + 0.791$	0.997
	1,4-Xylene	95-47-6	0.009	92	6	$y = 19.2\chi + 0.791$	0.997
	1,2-Xylene	106-42-3	0.013	85	10	$y = 11.4\chi - 0.048$	0.995
	n-Butylbenzene	104-51-8	0.009	91	5	$y = 18.5\chi + 0.629$	0.997
	sec-Butylbenzene	135-98-8	0.005	89	6	$y = 21.3\chi + 1.08$	0.997
	tert-Butylbenzene	98-06-6	0.024	93	6	$y = 13.5\chi + 0.070$	0.996
	n-Propylbenzene	103-65-1	0.103	82	9	$y = 24.0\chi + 1.02$	0.997
	Isopropylbenzene	98-82-8	0.006	86	8	$y = 15.2\chi - 0.124$	0.996
	p-Isopropyltoluene	89-83-8	0.087	97	8	$y = 1.51\chi + 0.057$	0.995
	Naphthalene	91-20-3	0.069	93	8	$y = 1.67\chi + 1.080$	0.996
	Bromobenzene	108-86-1	0.088	85	10	$y = 4.66\chi + 0.110$	0.996
	Chlorobenzene	108-90-7	0.769	89	8	$y = 5.51\chi - 0.618$	0.995
	2-Chlorotoluene	95-49-8	0.059	93	6	$y = 11.3\chi + 0.209$	0.996
	4-Chlorotoluene	106-43-4	0.061	96	10	$y = 10.2\chi + 0.164$	0.995
	1,2-Dichlorobenzene	95-50-1	0.026	94	5	$y = 6.86\chi - 0.197$	0.995
	1,3-Dichlorobenzene	541-73-1	0.016	93	6	$y = 6.92\chi - 0.118$	0.995
	1,4-Dichlorobenzene	106-46-7	0.005	89	6	$y = 21.3\chi + 1.08$	0.997
	1,2,4-Trimethylbenzene	95-63-6	0.063	93	6	$y = 13.5\chi + 0.070$	0.996
	1,3,5-Trimethylbenzene	108-67-8	0.029	83	7	$y = 13.1\chi - 0.145$	0.996
	1,2,3-Trichlorobenzene	87-61-6	0.085	90	7	$y = 5.34\chi + 0.199$	0.996
	1,2,4-Trichlorobenzene	120-82-1	0.064	87	8	$y = 5.26\chi + 0.198$	0.995

MDL: method detection limit (μg/l), REC: recovery (%), RSD: relative standard deviation (%)

TABLE 2. VOC concentrations and detection rates in Perlis, Kedah, Penang and Perak

Group	VOC	States	n	Detection rate (%)	Concentration (µg/L)			National Guideline (µg/L)	+Carcinogen Class (EPA)
					Mean	Min	Max		
Alkenes	*cis & trans-* 1,2-DCE	Perlis	15	33	6.32	ND	30.80	50	D
		Kedah	129	49	7.45	ND	16.30		
		Penang	184	66	8.61	ND	48.30		
		Perak	205	25	3.7	ND	26.20		
	TCE	Perlis	15	40	0.17	ND	2.00	70	B_2
		Kedah	129	39	0.14	ND	4.40		
		Penang	184	34	0.15	ND	7.60		
		Perak	205	49	0.11	ND	3.20		
Alkanes	$CHCl_3$	Perlis	15	100	13.21	ND	78.40	200	B_2
		Kedah	129	100	31.22	ND	176.90		
		Penang	184	100	21.34	ND	148.20		
		Perak	205	100	28.07	ND	290.50		
	$CHCl_2Br$	Perlis	15	40	1.09	ND	5.80	60	B_2
		Kedah	129	45	2.92	ND	37.70		
		Penang	184	55	1.48	ND	17.20		
		Perak	205	42	0.92	ND	20.50		
	$CHCLBr_2$	Perlis	15	87	0.81	ND	7.70	100	C
		Kedah	129	63	0.38	ND	2.80		
		Penang	184	53	0.23	ND	2.60		
		Perak	205	43	0.10	ND	1.00		
	1,2-DBA	Perlis	15	73	0.31	ND	0.90	0.4	B_2
		Kedah	129	65	0.19	ND	0.9		
		Penang	184	68	0.56	ND	13.5		
		Perak	205	59	0.12	ND	1.0		
Aromatics	Benzene	Perlis	15	20	1.45	ND	7.8	10	A
		Kedah	129	34	0.79	ND	10.8		
		Penang	184	15	0.63	ND	9.8		
		Perak	205	18	0.93	ND	10.8		
	Toluene	Perlis	15	20	0.05	ND	0.5	700	D
		Kedah	129	24	0.06	ND	1.0		
		Penang	184	42	0.19	ND	1.3		
		Perak	205	32	0.09	ND	1.6		
	Ethylbenzene	Perlis	15	33	0.03	ND	0.1	300	D
		Kedah	129	9	0.06	ND	2.7		
		Penang	184	29	0.08	ND	1.4		
		Perak	205	19	0.02	ND	0.3		
	Chlorobenzene	Perlis	15	60	0.44	ND	1.5	300	D
		Kedah	129	52	0.23	ND	8.9		
		Penang	184	40	0.12	ND	2.1		
		Perak	205	62	0.16	ND	2.9		
	1,4-DCB	Perlis	15	87	0.29	ND	1.5	300	C
		Kedah	129	61	0.84	ND	12.5		
		Penang	184	77	0.37	ND	4.1		
		Perak	205	38	0.06	ND	0.5		
	1,2-DCB	Perlis	15	47	0.22	ND	2.6	1000	D
		Kedah	129	22	0.09	ND	2.4		
		Penang	184	56	0.19	ND	3.9		
		Perak	205	5	0.01	ND	0.4		

+Carcinogen class: A: Human carcinogen with sufficient evidence; B_2: Probable human carcinogen with a combination of sufficient evidence in animals and inadequate data in humans; C: Possible human carcinogen based on limited evidence of carcinogenicity in animals in the absence of human data; D: Not classified based on inadequate evidence of carcinogenicity from animal data

TABLE 3. VOC concentrations and detection rates in Selangor, the Federal Territory,
Negeri Sembilan and Melaka

Group	VOC	States	n	Detection rate (%)	Concentration (µg/L)			National Guideline (µg/L)	+Carcinogen Class (EPA)
					Mean	Min	Max		
Alkenes	*cis & trans-* 1,2-DCE	Selangor	130	35	1.86	ND	53.10	50	D
		Federal T.	31	39	3.89	ND	36.140		
		Ngr Sembilan	133	37	4.58	ND	36.90		
		Melaka	41	71	7.22	ND	64.20		
	TCE	Selangor	130	23	0.07	ND	3.00	70	B_2
		Federal T.	31	36	0.38	ND	3.50		
		Ngr Sembilan	133	35	0.16	ND	3.50		
		Melaka	41	24	0.09	ND	1.00		
Alkanes	$CHCl_3$	Selangor	130	100	21.21	ND	190.90	200	B_2
		Federal T.	31	100	15.26	ND	100.30		
		Ngr Sembilan	133	100	24.10	ND	134.40		
		Melaka	41	100	28.71	ND	124.40		
	$CHCl_2Br$	Selangor	130	48	1.39	ND	51.50	60	B_2
		Federal T.	31	39	0.77	ND	8.80		
		Ngr Sembilan	133	39	3.55	ND	42.60		
		Melaka	41	34	10.13	ND	65.90		
	$CHCLBr_2$	Selangor	130	59	0.19	ND	4.00	100	C
		Federal T.	31	68	0.19	ND	1.80		
		Ngr Sembilan	133	87	0.98	ND	4.20		
		Melaka	41	78	2.41	ND	6.20		
	1,2-DBA	Selangor	130	55	0.12	ND	0.80	0.4	B_2
		Federal T.	31	65	0.19	ND	1.80		
		Ngr Sembilan	133	83	0.44	ND	1.40		
		Melaka	41	59	0.15	ND	0.40		
Aromatics	Benzene	Selangor	130	25	1.05	ND	9.40	10	A
		Federal T.	31	36	1.51	ND	9.60		
		Ngr Sembilan	133	25	0.50	ND	8.20		
		Melaka	41	22	0.75	ND	5.60		
	Toluene	Selangor	130	30	0.09	ND	1.30	700	D
		Federal T.	31	29	0.05	ND	0.60		
		Ngr Sembilan	133	75	0.32	ND	7.60		
		Melaka	41	27	0.04	ND	0.20		
	Ethylbenzene	Selangor	130	29	0.06	ND	1.40	300	D
		Federal T.	31	10	0.01	ND	0.10		
		Ngr Sembilan	133	23	0.02	ND	0.30		
		Melaka	41	5	0.01	ND	0.20		
	Chlorobenzene	Selangor	130	39	0.11	ND	1.30	300	D
		Federal T.	31	65	0.13	ND	0.40		
		Ngr Sembilan	133	77	0.49	ND	10.50		
		Melaka	41	66	0.14	ND	1.00		
	1,4-DCB	Selangor	130	62	0.78	ND	18.60	300	C
		Federal T.	31	65	0.21	ND	1.10		
		Ngr Sembilan	133	72	0.22	ND	3.40		
		Melaka	41	78	0.23	ND	0.80		
	1,2-DCB	Selangor	130	5	0.01	ND	0.20	1000	D
		Federal T.	31	13	0.07	ND	1.90		
		Ngr Sembilan	133	14	0.06	ND	1.80		
		Melaka	41	32	0.13	ND	0.90		

+Carcinogen class: A: Human carcinogen with sufficient evidence; B_2: Probable human carcinogen with a combination of sufficient evidence in animals and inadequate data in humans; C: Possible human carcinogen based on limited evidence of carcinogenicity in animals in the absence of human data; D: Not classified based on inadequate evidence of carcinogenicity from animal data

TABLE 4. VOC concentrations and detection rates in Kelantan, Terengganu, Pahang and Johor

Group	VOC	States	n	Detection rate (%)	Concentration (µg/L)			National Guideline (µg/L)	+Carcinogen Class (EPA)
					Mean	Min	Max		
Alkenes	cis & trans-1,2-DCE	Kelantan	121	47	5.22	ND	46.50	50	D
		Terengganu	130	47	3.15	ND	47.60		
		Pahang	234	54	5.54	ND	45.60		
		Johor	152	68	6.92	ND	47.60		
	TCE	Kelantan	121	41	0.12	ND	0.90	7	B_2
		Terengganu	130	39	0.30	ND	5.20		
		Pahang	234	46	0.35	ND	5.80		
		Johor	152	38	0.51	ND	60.20		
Alkanes	$CHCl_3$	Kelantan	121	27	23.57	ND	139.50	200	B_2
		Terengganu	130	68	37.78	ND	182.50		
		Pahang	234	83	22.61	ND	178.10		
		Johor	152	91	36.80	ND	187.50		
	$CHCl_2Br$	Kelantan	121	57	1.62	ND	13.30	60	B_2
		Terengganu	130	44	3.57	ND	36.00		
		Pahang	234	51	2.59	ND	43.00		
		Johor	152	59	6.21	ND	50.10		
	$CHCLBr_2$	Kelantan	121	54	0.15	ND	1.80	100	C
		Terengganu	130	81	0.53	ND	6.20		
		Pahang	234	65	0.34	ND	13.70		
		Johor	152	55	0.48	ND	11.00		
	1,2-DBA	Kelantan	121	76	0.17	ND	1.30	0.4	B_2
		Terengganu	130	70	0.18	ND	0.80		
		Pahang	234	82	0.26	ND	0.90		
		Johor	152	78	0.25	ND	0.90		
Aromatics	Benzene	Kelantan	121	7	0.46	ND	9.80	10	A
		Terengganu	130	25	1.42	ND	12.90		
		Pahang	234	15	0.86	ND	15.60		
		Johor	152	9	0.50	ND	9.50		
	Toluene	Kelantan	121	46	0.13	ND	2.70	700	D
		Terengganu	130	60	0.25	ND	2.60		
		Pahang	234	37	0.42	ND	34.50		
		Johor	152	14	0.12	ND	0.40		
	Ethylbenzene	Kelantan	121	25	0.03	ND	0.30	300	D
		Terengganu	130	46	0.14	ND	0.90		
		Pahang	234	30	0.06	ND	0.70		
		Johor	152	7	0.01	ND	0.40		
	Chlorobenzene	Kelantan	121	60	0.39	ND	5.00	300	D
		Terengganu	130	81	0.49	ND	8.90		
		Pahang	234	73	0.31	ND	2.90		
		Johor	152	36	0.08	ND	1.20		
	1,4-DCB	Kelantan	121	52	0.42	ND	9.50	300	C
		Terengganu	130	70	0.30	ND	1.50		
		Pahang	234	79	2.55	ND	64.10		
		Johor	152	74	0.40	ND	15.40		
	1,2-DCB	Kelantan	121	41	0.43	ND	10.50	1000	D
		Terengganu	130	11	0.11	ND	3.20		
		Pahang	234	42	0.29	ND	6.40		
		Johor	152	40	0.17	ND	7.40		

+Carcinogen class: A: Human carcinogen with sufficient evidence; B_2: Probable human carcinogen with a combination of sufficient evidence in animals and inadequate data in humans; C: Possible human carcinogen based on limited evidence of carcinogenicity in animals in the absence of human data; D: Not classified based on inadequate evidence of carcinogenicity from animal data

trichloroacetic acid and acetaldehyde (Kuo et al. 1997). THM concentrations can be affected by factors including the precursor, water source, their properties (e.g. total organic carbon, contact time, chlorine dose and pH) (Md. Pauzi et al. 2003), and how the water supply facility treats the water source. Another VOC under the alkanes group which had significant abundance was 1,2-dibromoethane with more than 55% detection rate and mean concentrations of 0.12 to 0.56 μg/L in all states. The presence of 1,2-dibromoethane in drinking water is probably due to contamination of surface water sources because this compound is persistent and is categorised as having degradation rates of class 7, which implies that the mean half-life is about 8 months (Aggazzotti & Predieri 1986).

The detection rate percentages of aromatic compounds occurring in drinking water samples analysed were benzene (7-36%), toluene (14-75%), ethylbenzene (5-46%), chlorobenzenes (36-81%), 1,4-dichlorobenzene (38-87%) and 1,2-dichlorobenzene (5-56%). The presence of these compounds in drinking waters may be attributed to petroleum refineries, solvent plants and agriculture activities in Peninsular Malaysia.

Under the alkenes group, the detection rate of 1,2-dichloroethylenes (cis and trans) and trichloroethylene in all states was in the range of 25-71% and 23-49%, respectively. The mean concentration of both alkenes ranged from 1.86-8.61 μg/L for 1,2-dichloroethylenes and 0.07-0.51 μg/L for trichloroethylene. 1,2-dichloroethylenes are generally used as solvents in rubber manufacturing, and trichloroethylene is usually associated with dry cleaning operations and a solvent in numerous industries.

Notably, the levels and types of VOCs detected in this study did not seem to have any strong correlation with the level of development of the state from which the samples originated. Less developed states of Peninsular Malaysia such as Perlis, Kedah, Kelantan and Terengganu, did not have fewer VOC contaminants than the more developed states of Selangor, Federal Territory of Kuala Lumpur, Penang and Johor. Whether this was due to the characteristics of the VOCs themselves, such as their volatility, persistency, and the wide spread usage of chlorine in water treatment plants has yet to be understood.

Conclusion

Samples of Malaysian drinking water studied were contaminated with THMs, alkenes and aromatics VOCs. However the mean concentration of compounds in all groups did not exceed the maximum contaminant levels stipulated in the National Guideline for Drinking Water Quality 2000. Because the contaminants came from substances used in various industries and manufacturing processes, or as an unintended result of the disinfection processes, their presence, regardless of their concentration, indicates the need for more stringent regulatory measures and proper environmental management.

References

AOAC. 1993. *AOAC Peer Verified Methods Program, Manual on Policies and Procedures*. Arlington, VA: AOAC International.

Faust, S.D. & Aly, O.M. 1998. *Chemistry of Water Treatment*. 2nd ed. New York: Lewis Publishers.

Golfinopoulos, S.K., Kostopoulou, M.N. & Lekkas, T.D. 1998. Volatile halogenated organics in the water supply system in Athens, Greece. *Wat. Res.* 23(6): 1811-1818.

Kuo, H.W., Chiang, T.F., Lo, I.I., Lai, J.S., Chan, C.C. & Wang, J.D. 1997. VOC concentration in Taiwan's household drinking water. *Sci. Total Environ.* 208: 41-47.

Md Pauzi, A., Yew, C.H. & Mohamad Salleh, R. 2003. Formation, modelling and validation of trihalomethanes (THM) in Malaysian drinking water: a case study in the districts of Tampin, Negeri Sembilan and Sabak Bernam, Selangor, Malaysia. *Wat. Res.* 37: 4637-4644.

Md. Pauzi, A., Yew, C.H, Mohamad Salleh, R. & Rahmah, A. 2002. Validation of solid phase microextraction technique for analysis of Trihalomethanes (THMs) in Malaysian drinking water. *Malaysian Journal of Chemistry* 4(1): 27-34.

Squillace, P.J., Moran, M.J., Lapham, W.W., Price, C.V., Clawges, R.M. & Zogorski, J.S. 1999. Volatile organic compounds in untreated ambient groundwater of the United States, 1985 – 1995. *Environ. Sci. Technol.* 33 (23): 4176-4187.

Squillace, P.J., Scott, J.C., Moran, M.J., Nolan & Kolpin, D.W. 2002. VOCs, pesticides, nitrate, and their mixtures in groundwater used for drinking water in the United States. *Environ. Sci. Technol.* 36(9): 1923-1930.

Sukiman, S. & Md. Pauzi, A. 1993. Chemical quality of Malaysian drinking water sources. In *Drinking Water Quality: Microbiological and Public Health Aspects*, edited by Jangi, M.S. Bangi: Universiti Kebangsaan Malaysia.

Wercinski, S.A.S. 1999. *Solid Phase Microextraction: A Practical Guide*. New York: Marcel Decker, Inc.

School of Chemical Sciences & Food Technology
Faculty of Science and Technology
43600 UKM Bangi, Selangor D.E.
Malaysia

*Corresponding author; email: mpauzi@ukm.my