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Surveys of Volatile Organic Compounds in Soil and Groundwater at Industrial Sites in Taiwan

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In recent years, rapid industrialization in Taiwan has led to an economic boom, but improvement of living standard also accompanied with deterioration of environmental quality. Groundwater and/or soil contamination has been a major problem in developed countries, however, most studies conducted in Taiwan focused on general quality or inorganic pollution (Liu and Shu, 1994; Chu and Shen, 1994). There were only a few efforts dealt with particular organic chemicals, such as volatile or semi-volatile organic compounds. A 2,4-dichlorophenol concentration up to 103 ug/L was reported in one of soil samples collected near a petrochemical industry area (Chang *et al.*, 1994). Yin and Su (1996) found different levels of phthalate esters in drinking water from a groundwater source. Groundwater samples collected from a well in a high school in southern Taiwan contained 10.45 ug/L of total trihalomethane (THM) (Kuo *et al.*, 1995). But there is no systematic investigation conducted to investigate chemical contamination in either soil or groundwater in industrial areas, at which this type of pollution is prone to occur. The purpose of this preliminary study was to survey soil and groundwater contamination in different industrial sites in Taiwan. These sites covered chemical, electronic, and refining industries. Chemicals of concern were volatile organic compounds (VOCs) because of their quantity in use and potential for posing environmental hazard.

MATERIALS AND METHODS

There were a total of 30 industrial sites investigated in this study. Figure 1 shows the locations of these sites. They included 8 chemical and petrochemical industrial districts, 2 technology industrial parks, 11 general industrial districts, 2 metal processing areas, 2 oil refinery plants, 1 pesticide manufacturing, and 4 landfills. Three to six soil sampling points were randomly selected within each site. Soil samples at three depths (0.5,1.5 and 3 m) were taken at each point, and the sampling was conducted using a direct push method (Geoprobe Inc., 1998). Groundwater samples were obtained from the existing monitoring wells on the 30 sites. Each soil and groundwater sampling points were taken twice at two different times. Upon collection, samples were stored in 4°C and transported back to our laboratory for pretreatment processes. Sixty volatile organic compounds were analyzed according to USEPA SW846 Method 5035 using purge and trap (USEPA, 1994) and Method 8260B using GC/MSD (USEPA, 1996).

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RESULTS AND DISCUSSION

Figures 2 and 3 show the detection frequency of volatile organic compounds in groundwater and soil samples, respectively. As presented in Figure 2, volatile organic compounds frequently found in the groundwater on the contaminated industrial sites in Taiwan are trichloromethane, 1,3,5-trimethylbenzene, 2-chlorotoluene, 4-chlorotoluene, vinyl chloride, tert-butyl methyl ether, 1,1-dichloroethene, 1,2- dichloroethane, trichloroethene, toluene, 1,1- dichloroethane, trichlorofluoromethane, benzene, chloromethane, 1,2,4-trimethylbenzene, styrene. These VOCs were found in more than 3% of all the groundwater samples. Trichloromethane was found to be the most frequently detected among them, with a detection percentage of more than 15% of all samples.

Figure 3 shows that similar patterns of volatile organic compounds were found in the soil on the contaminated industrial sites in Taiwan, as compared to those in groundwater. Volatile organic compounds commonly found in soil were toluene, trichloroethene, m-xylene and p-xylene, tert-butyl methyl ether, 1,3,5-trimethyl-benzene, 2-butaone, ethylbenzene, naphthalene, 2-chlorotoluene, styrene, tetra-chloroethene, 4-chlorotoluene, 1,2,4-trimethylbenzene, 4-iso-propyltoluene, n-butylbenzene, (e)-1,2-dichloroethene, 1,2-dichloroethene. The compound with the highest detection frequency was the toluene (18%).

This investigation also identified 7 highly contaminated wells in 6 different locations. The levels of volatile organic compounds in the some of the groundwater samples taken from these 7 wells exceeded more than 10 times of either the standard of a water source for potable use set by Taiwan EPA (1997) or recommended cleanup criteria for contamination (Buonicore, 1996).

Table 1 shows the concentrations and the types of contaminants determined in these water samples. Three chemicals with high concentrations were found in a well (1-C045) situated in a petrochemical plant (Site 1). They were vinyl chloride, (z)-1,2-dichloroethene, and 1,2-dichloroethane. The highest concentration detected was 100,000 ug/L for vinyl chloride. This level is 50,000 times higher than the national standard (2 ug/L). Concentrations of the other two compounds are also 100 to 1000-fold higher than the standards (Site 1). High concentrations of benzene were found in the well 2-C023, which is located in a steel mill (Table 1, Site 2). Benzene concentrations of the two water samples collected from 2-C203 at different times were 110 and 48 ug/L, respectively. These levels are much higher than the value set by Taiwan EPA (5 ug/L). In a refinery plant (Table 1, Site 3), benzene concentrations of 420 and 1600 ug/L were found in a monitoring well (3-T27). Styrene concentrations as high as 5,400 ug/L were detected in one of the water samples collected from the well 4-Y2 located in a plastic manufacturing plant (Table 1, Site 4). Trichloroethene concentrations of 110 and 90 ug/L were found in a monitoring well (5-S19) at a technology industrial park (Table 1, Site 5), and were about 20 times higher than the national standard of 5 ug/L for a source of drinking water.

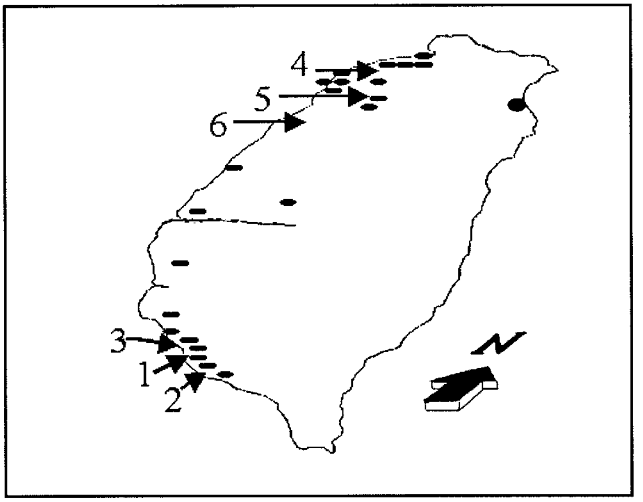

Figure 1. Geographic distribution of 30 sites investigated in the Taiwan island. Numbered locations (1-6) were places with high levels of VOCs detected in groundwater from the sampling wells, and were corresponding to those in Table 1.

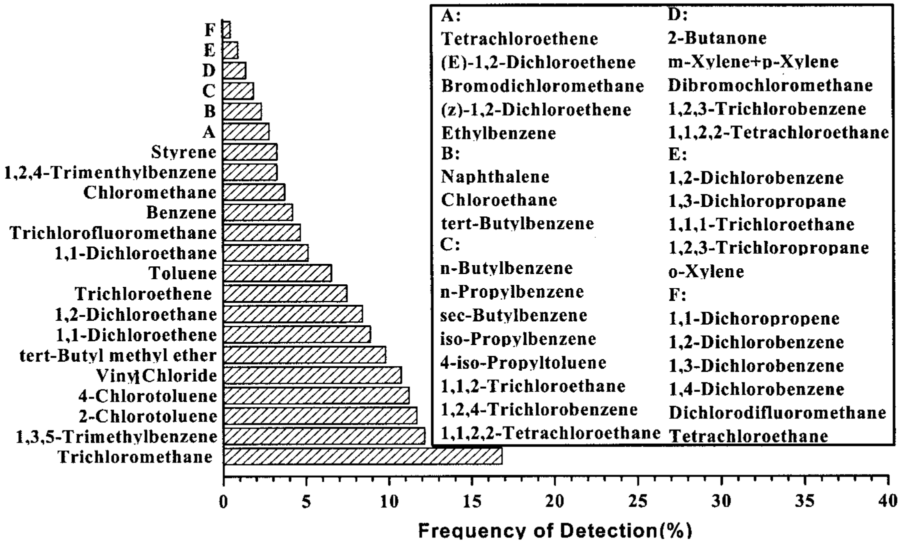

Figure 2. VOCs detection frequency (%) in a total of 214 groundwater samples.

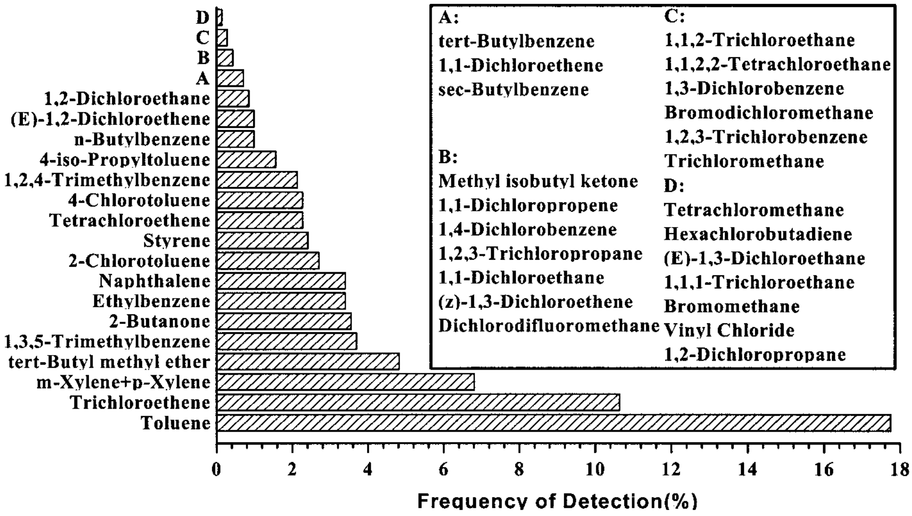

Figure 3. VOCs detection frequency (%) in a total of 705 soil samples.

Groundwater samples from the 6-A12 well, which situated in a petrochemical plant (Table 1, Site 6) manufacturing vinyl chloride and other petrochemicals, were found to be polluted with high levels of various VOCs. The compound with the highest concentration was 1,2-dichloroethane with a level up to 160,000 ug/L. Compared to the national standard of 5 ug/L, this level exceeds by 32,000-fold. Other chemicals found at this site also showed various degrees of contamination. For example, vinyl chloride and trichloromethane were also detected at levels as high as 23,000 and 3,800 ug/L, while the concentration of 1,1-dichloroethane was found to be in a range of several-hundred ppb (ug/L). Groundwater samples from the 6-I well located in the vicinity of the Site 6 (not inside the plant area) also contained high levels of vinyl chloride with concentrations of 23,000 and 2,500 ug/L for the two samples. This site is currently under remedial action by local government because the groundwater used as a source of drinking water for the local residents.

VOCs in soil from all sampling locations were found to be at levels close to or lower than the regulatory agency (Buonicore, 1996), and the results were not reported here. It should be noted that no apparent correlation of chemical profiles in groundwater and soil samples taken from a particular site was observed in this investigation, especially the 7 wells with VOCs contamination. It is possible due to fairly large areas studied and relatively small sample sizes within a site, the locations of the sampling points for both soil and groundwater, or behaviors of chemicals within the two environmental medians.

To summarize the results of this preliminary survey, VOC contaminants found in groundwater were related to the type of industries. Groundwater contamination cases were found mostly in petrochemical and refining industries. Water samples taken from six of the 30 sites were found to contain tremendously high levels of various pollutants, while analysis of some soil samples at the same site showed only low levels of VOCs. The outcome of this study deserves more attention because use of groundwater as drinking water source is still prevalent at some of the rural areas in Taiwan, where public water supply system is not available. A more thorough study is currently in progress at the sites of the 7 VOCs-contaminated wells to determine the source(s) and severity of the pollution.

Table 1. Types and levels of VOCs found in six different wells at different industrial sties.

Site[a]	Well No.	Contaminants	Concentration (ug/L)[d] 1(1999/3)	2(1999/4)	National Standard(ug/L)
1	1-C045	vinyl chloride	100,000	22,000	2[b]
		(z)-1,2-dichloroethene	750	2,400	70[c]
		1,2- dichloroethane	510	1,500	5[b]
2	2-C023	benzene	110	48	5[b]
3	3-T27	benzene	420	1,600	5[b]
4	4-Y2	styrene	2,800	5,400	1,000[c]
5	5-S19	trichloroethene	110	90	5[b]
6	6-I	vinyl chloride	23,000	2,500	2[b]
	6-A12	vinyl chloride	23,000	3,300	2[b]
		1,1-dichloroethene	590	430	7[b]
		(e)-1,2-dichloroethene	2,400	2,300	100[c]
		1,1-dichloroethane	1,000	900	70[c]
		(z)-1,2-dichloroethene	2,200	2,300	70[c]
		trichloromethane	3,200	3,800	6[c]
		trichloroethene	1,100	2,400	5[b]
		1,1,2-trichloroethane	700	1,800	5[c]
		1,2- dichloroethane	100,000	160,000	5[b]

[a] Site numbers are corresponding to location illustrated in Figure 1.
[b] Standards for the source of drinking water set by Taiwan EPA.
[c] Cleanup criteria recommended by ASTM (Buonicore, 1996).
[d] There were two samples at different times for each sampling point.

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