Risk Characterization of Organic Air Toxics in an Industrial City in Taiwan

Jiun-Horng Tsai, Yung-Chen Yao, Li-Peng Chang and Hui-Fen Ye
Department of Environmental Engineering, National Cheng-Kung University, Tainan, 70101, Taiwan, R.O.C.
jhtsai@mail.ncku.edu.tw

ABSTRACT

Organic air toxics have caused attention to public in Taiwan since mid-1990. This study selected benzene and toluene as the target pollutants for risk characterization in Kaohsiung, the biggest industrial city in Taiwan, by simulation. Both of emissions from stationary and mobile sources are included. Risk characterization of benzene (carcinogen) and toluene (non-carcinogen) were evaluated by air dispersion model (industrial source complex model, ISC3) simulation and airborne exposure assessment. Cancer risk is characterized by maximum individual cancer risk (MICR) and non-carcinogen risk is characterized by hazardous index (HI).

Emission estimation of benzene and toluene were approximate 4,080 and 7,600 ton/year, respectively. Mobile sources accounted for approximate 68% and 74% of benzene and toluene, and the stationary sources contributed to the others. The result indicated cancer risk imposed by stack and fugitive sources which were higher than target limit (10^{-6}). Health risk from fugitive sources is higher than the impact cause by stack emissions, with MICR of 1480×10^{-6} and 60×10^{-6}, respectively. Cancer risk is resulted by benzenes from mobile sources also exceed target limit, with MICR of 260×10^{-6}. Non-carcinogen impacts are caused by toluene indicated that the HI value was less than 0.1 for both of stationary and mobile sources. That means no significant adverse health impact effect to people. The stimulation also indicated the high risk ($>100\times10^{-6}$) imposed on the vicinity of stationary source. Approximate 40% of population was exposure to the high risk level caused by the mobile sources. However, stationary source caused a significant impact in its vicinity, which was defined as a hot-spot.

Key words: organic air toxics, health risk, model simulation

INTRODUCTION

This study was designed to study the potential risk characterization of air toxics in Kaohsiung, the biggest industrial urban area in Southern Taiwan. A map is shown in Figure 1.[1] The area is approximate three thousands kilometer square. Two-thirds of the area is hilly terrain. The Kaohsiung metropolitan area has a population of approximate 2.8 million people, thus assuring sufficient source strength of area and mobile sources in the region. In addition, the region does contain large industrial point sources such as refineries and chemical plants. Due to bad environmental condition, the air basin has been classified as a non-attainment region of ozone and PM10 since 1990's. In 2002, there was approximate 8% of the pollutant standard index (PSI) higher than 100 in this air basin [2]. Both of ozone and particulate matter are related with volatile organic compounds (VOCs), and some of VOCs are known harmful to human health.

Exposure to air toxics, including VOCs, is believed to result in significant risks to human health. Air toxics have caused attention of the public since mid-1990 in Taiwan. Taiwan Environmental Protection Administration (TEPA) has implemented investigation project

about air toxics in industrial area in early 1990's. The results indicated that emission of volatile organic compounds in the majority in Taiwan, are important than heavy metal, acid gas and fluoride. This progress shows air toxics has to be controlled in Taiwan, but so far it hasn't been done yet.
In order to understand the risk characterization for the organic air toxics has to be simulated by model tool. Many air quality models are used to estimate urban ambient pollutant concentrations. Refer to "Criteria for Inputs for Risk Assessment Using Screening Air Dispersion Modeling", published by California Air Resources Board, some acceptable models are the U.S. EPA SCREEN3 model and the U.S. EPA ISC3 model.[3] This study applies the Industrial Source Complex Short Term (ISCST3) model, a steady-state Gaussian plume model used to assess pollutant impacts from multiple point, area and mobile sources.[4] This model was selected because it is readily available and widely used to model non-reactive pollutants.[5]

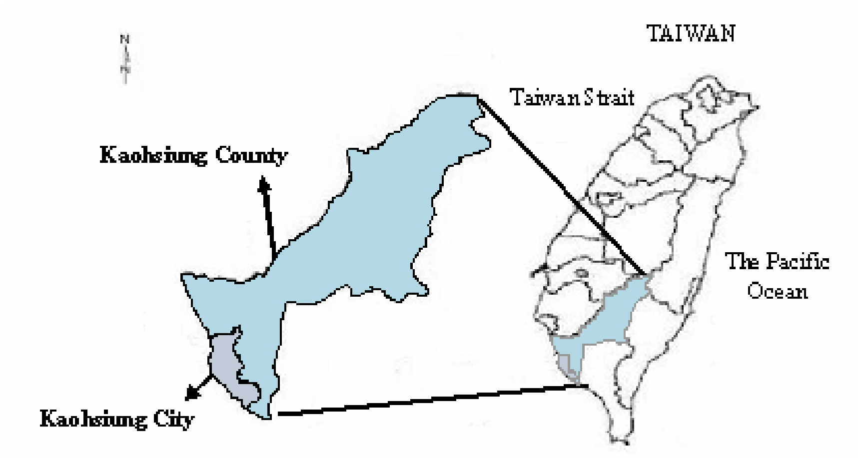

Fig.1.Geographical site of Kaohsiung metropolitan area

VOCs associated with the exposure to industry and mobile emissions are concerned because of their toxicity. The target VOCs are known as petroleum chemical industry and tailpipe emission markers are benzene, toluene, ethylbenzene, *o*-xylene, *m*-xylene and *p*-xylene. This study is selected benzene and toluene as the target pollutants for risk characterization in Kaohsiung area. Benzene is a known human carcinogen and is also identified as one of the hazardous air pollutants posing the greatest risk to human health from inhalation exposure.[6-7] Toluene is classified in Group D (not classifiable as to human carcinogenicity) by IRIS. IARC states that toluene is not classifiable as to its carcinogenicity to humans (Group 3). There is inadequate evidence in humans and evidence suggesting a lack of carcinogenicity of toluene in experimental animals. These studies have identified neurologic effects.[8]
The stationary sources and on-road mobile source emission are contributed the great part of emission inventory in the Kaohsiung Area. This paper discusses risk characterization of target organic air toxics (benzene and toluene) in Kaohsiung area by dispersion model simulation, industrial source complex model (ISC). Both of emissions from stationary and mobile sources are included. According to result of emission inventory of Kaohsiung area, benzene is the highest unit risk compound and toluene has the maximum emission.[9] Cancer risk is characterized by maximum individual cancer risk and non-carcinogen risk is characterized by hazard index.

METHODOLOGY

In order to evaluate air toxics risk for resident in industrial area, it is necessary to collect the emission data from stack, fugitive and mobile sources, and to know the major target compounds that exposed in study area. Emissions from stack (point source), fugitive sources (area source) and on-road vehicles (line source) were run model respectively. The framework of this study is shown in Figure 2.

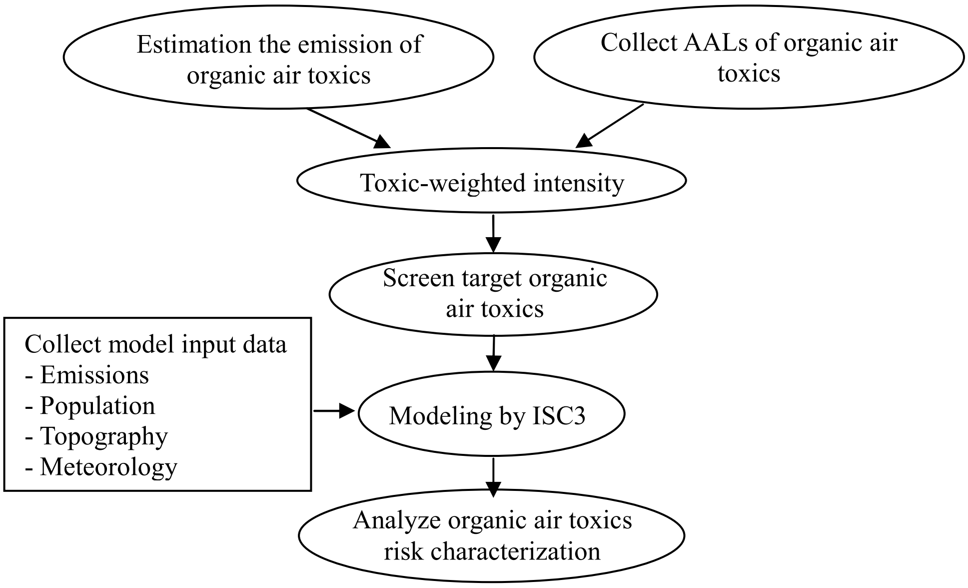

Fig.2.Framework of risk characterization of organic air toxics in Kaohsiung, Taiwan

1. Collect elements of health risk assessment for organic air toxics

According to the procedures of risk assessment including two groups of air toxics: the carcinogens and non-carcinogens that establishment by U.S. EPA.[10] For evaluating the air toxics exposure of residents in Kaohsiung, the data required for performance risk assessment were collected in the beginning stage. The required data is as follows:

- **Estimation the emission of organic air toxics**

TEPA has developed a Taiwan air pollutant Emission Data System (TEDS) for PM, NOx, SOx, THC, NMHC and CO. TEDS consists of emission inventory from stationary, mobile, and area/fugitive sources in the base year 2000. This study had been conducted on the basis of THC emission data of TEDS to estimate the specific organic species emission in Kaohsiung. To convert total VOCs emissions to species emissions by using emission factor of Factor Information Retrieval System (FIRE 6.22) in stationary sources. For on-road mobile sources, TEDS emissions data are divided into several subcategories: motorcycles, gasoline vehicles, diesel trucks and buses, and off-road emissions. The mobile source emissions are measured as follows:

$$E = A / B \quad (1)$$

$$H = E \times G \quad (2)$$

A: Air toxic emission factor from exhaust (g/km)
B: THC emission factor from exhaust (g/km)
E: Ratio of HAP species and THC

G: Total emission from on-road mobile sources in TEDS (ton/year)
H: Air toxic emission from on-road mobile sources (ton/year)

- **Screen target organic air toxics**

This study created a toxic-weighed intensity (TWI) to be an index to evaluate significant air toxics in Kaohsiung area. Its unit is cube meter per day (m^3/d):

$$\mathrm{TWI} = \frac{\text{Emission for compound A}}{\text{Ambient air level of compound A}} \qquad (3)$$

Ambient air levels (AALs) was adopted advice of TEPA project.[11] Use TWI of each organic compound for stack, fugitive and mobile sources, and then to sort the value to screen the most significant air toxics form stationary and mobile sources.

- **Collect input data for model**

The data of target air toxics emission data, population, topography and meteorology are required for ISC3 model and risk assessment process, with all the correct switches. Air dispersion modeling must use worst-case meteorological conditions and the most health protective parameters applicable to the facility.[3] In order to get conservative condition, this paper precedes a trial run by using meteorological data from year 1996 to 2000 and THC emission of point source in TEDS for Kaohsiung area. The maximum simulation concentration appeared in meteorological data is year 1999.

- **Development health risk assessment process**

This study applies Maximum Individual Cancer Risk (MICR) and Hazardous Index (HI) to estimate risk in ambient for carcinogens and non-carcinogens. For carcinogens, annual concentration multiplied cancer risk to calculate MICR. For non-carcinogens, annual concentration is divided by ambient air level to calculate HI.

2. Analyze risk effect from different sources

Hazard risk analysis was conducted by annual maximum concentration and risk value of target pollutants. Target air toxics annual concentration from point, line and area sources was simulated by ISC3 model respectively.

- **Carcinogenic risk**

For carcinogens, annual concentration multiplied cancer risk of single compound to calculate MICR and compared with 10^{-6}. Cancer risk was adopted advice of TEPA.[11]

- **Non-carcinogenic risk**

For non-carcinogens, annual concentration is divided by ambient air level (AAL) to calculate HI. The HI compared with 1.0. AAL was adopted inhalation reference concentration (RfC), that advised by TEPA.[11]

RESULTS AND DISCUSSION

1. Target organic air toxics

The emission of air toxics and the TWI is based on the screen of target compounds. To analysis toxic-weighed of each organic compound for the top 50 stationary sources in Kaohsiung area, the highest toxic-weighed intensity compound is ethylene oxide, 627×10^{11} m^3/day, and then cholroethylene, 1,2-dichloroethane, benzene and formaldehyde. Ethylene oxide emission is only contributed 1.1% for the organic compounds in Kaohsiung area, but with very low AALs (0.008 $\mu g/m^3$). The emission may not be conspicuous, but the low AALs cause they have higher TWI. For on-road mobile sources, the (TWI) of top 3 volatile organic compounds are benzene, toluene and ethylbenzene in Kaohsiung area. Table 1 shows the TWI for main organic air toxics in Kaohsiung area. Integrate the results of TWI for stationary and mobile sources, benzene has the highest unit risk and toluene has the maximum emission. In addition, benzene and toluene are the common species of air toxics of both stationary and mobile source. This paper has chosen benzene and toluene as the target compounds to evaluate risk characterization.

Table 1. Toxic-weighed intensity (TWI) for organic air toxics in Kaohsiung area

Organic Air Toxics	TWI (m^3/day)			AALG* ($\mu g/m^3$)
	Stationary sources	Mobile sources	Total	
Benzene	67.1×10^{11}	$\mathbf{352\times10^{11}}$	419.10×10^{11}	0.096
Toluene	0.12×10^{11}	0.18×10^{11}	0.30×10^{11}	400
Xylene	0.002×10^{11}	0.006×10^{11}	0.008×10^{11}	5200
Ethylene oxide	$\mathbf{626.7\times10^{11}}$	---	626.70×10^{11}	0.008
Cholroethylene	253.0×10^{11}	---	253.00×10^{11}	0.01
1,2-Dichloroethane	130.1×10^{11}	---	130.10×10^{11}	0.04
Formaldehyde	39.6×10^{11}	---	39.60×10^{11}	0.08
Trichloroethylene	6.32×10^{11}	---	6.32×10^{11}	0.39

"*" AALG source: [13] TEPA,1998

2. Risk characterization of organic air toxics from stationary and mobile sources

(1) Carcinogens: benzene

The risk characterization of benzene for stationary and mobile sources in Kaohsiung area is shown in Table 2. Based on model estimation, ambient concentration of benzene from fugitive source has the maximum concentration and with the highest MICR. The stimulation also indicated the high risk ($>100\times10^{-6}$) imposed on the vicinity of stationary source. Benzene from gasoline vehicles poses the highest cancer population. Cancer risk resulted by benzenes were exceed target limit (10^{-6}) for all of stationary and mobile sources. The modeled benzene concentrations are shown in Figure 3.

- **Point sources**

The simulation result by ISC3 indicated benzene annual maximum concentration was 2.04 $\mu g/m^3$ from stack emission, multiplied by unit cancer risk, 2.9 $\times10^{-5}$ $(\mu g/m^3)^{-1}$ is 59 $\times10^{-6}$, this value is as a MICR of benzene. The location of the highest concentration is UTM coordinate (179,2506), which is located in central Kaohsiung city.

- **Area sources**

The simulation result indicated benzene annual maximum concentration was 51.1 $\mu g/m^3$ from fugitive emission, multiplied by unit cancer risk, the MICR value is $1{,}480\times10^{-6}$. The location of the highest concentration was UTM coordinate (188,2490), which is located in Linyuan petrochemical industrial district, the southern Kaohsiung country.

- **Line sources (on-road mobile sources)**

ISC3 simulation result indicated benzene annual maximum concentration was 6.0 $\mu g/m^3$ from gasoline vehicles, the MICR value is 174×10^{-6}. The location of the highest concentration was UTM coordinate (178,2502), which is located in Lingya District of Kaohsiung city, and high population density. For motorcycle, benzene annual maximum concentration was 1.8 $\mu g/m^3$, calculated MICR is 52×10^{-6}. The location of the highest concentration is UTM coordinate (178,2502. For diesel engine vehicles, benzene annual maximum concentration was 1.43 μg/m^3, MICR is 42×10^{-6}. The location has the highest concentration was UTM coordinate (182,2504), it was the intersection of Fongshan City of Kaohsiung County and Kaohsiung City, near the Kaohsiung Interchange of #1 Highway.

Table 2. Modeled benzene maximum concentration and MICR

Source Type		Max. modeled Concentration (μg/m^3)	Max. MICR
Stationary Source	Stack	2.04	60×10^{-6}
	Fugitive	51.14	1480×10^{-6}
On-road Mobile Source	Gasoline vehicle	6.0	170×10^{-6}
	Motorcycle	1.79	50×10^{-6}
	Diesel engine	1.43	40×10^{-6}
	Average	9.1	260×10^{-6}

MICR=concentration × unit risk Benzene: unit risk = $2.9\times10^{-5}(\mu g/m^3)^{-1}$

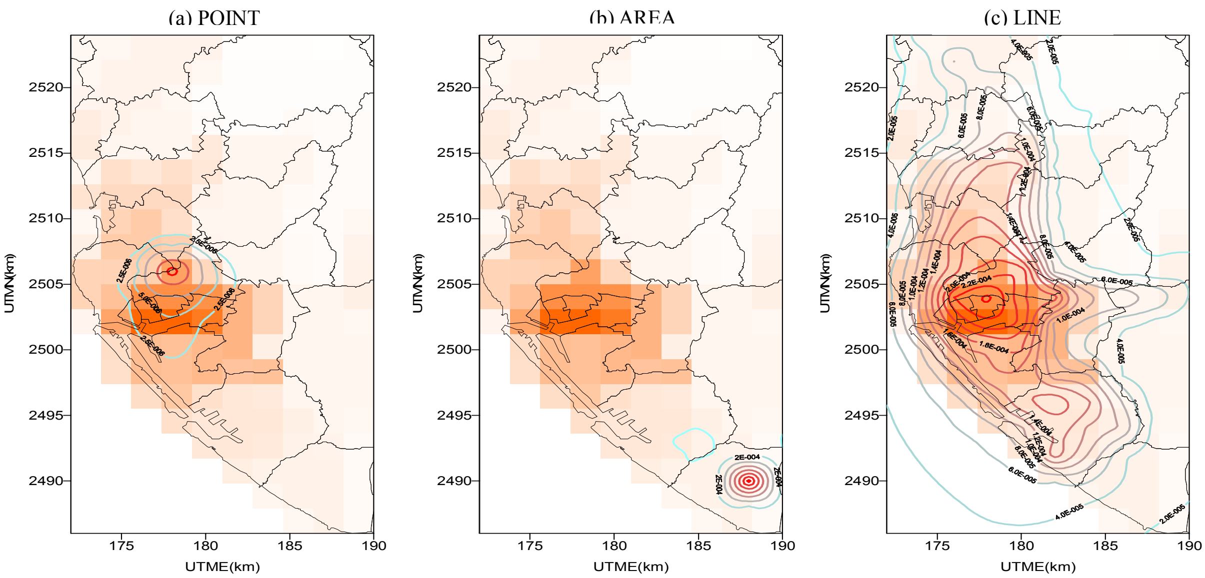

Fig.3.Benzene annual maximum concentration from (a) point, (b) area and (c) on-road mobile sources.

(2) Non-carcinogens: toluene

The risk characterization of toluene for stationary and mobile sources is shown in Table 3. Based on model estimation, ambient concentration of toluene from stack emission has the maximum concentration and the highest HI. The result indicated non-carcinogens impacts caused by toluene indicated that the HI value was less than 0.1 for all of stack, fugitive and on-road mobile sources. That means no significant adverse health impact effect to people. The modeled toluene concentrations in Kaohsiung area are shown in Figure 4.

- **Point sources**

The simulation result by ISC3 indicated toluene annual maximum concentration is 95.82 μg/m^3 from point sources, is divided by RfC (400 μg/m^3), HI value is 0.24. This value is as a hazard index (HI) of toluene. The location of the highest concentration is UTM coordinate (172,2524), location is Gangshan Township in Kaohsiung coutry.

- **Area sources**

The simulation result of area sources indicated toluene annual maximum concentration is

28.9µg/m^3, is divided by RfC (400µg/m^3),HI is 0.072. The location of the highest concentration is UTM coordinate (188,2490), which is located in Linyuan Township.

- **Line sources (on-road mobile sources)**

For non-carcinogens (toluene), the simulation result of gasoline vehicles indicated toluene annual maximum concentration was 11.5µg/m^3, is divided by RfC to obtained HI is 0.029. The location has the highest concentration is UTM coordinate (178,2504), which is located in Sinsing District in Kaohsiung city, and high population density. For motorcycle, the simulation result indicated toluene annual maximum concentrations 18.3µg/m^3 and HI is 0.011. The location of the highest concentration is UTM coordinate (178,2504). For diesel engine vehicles, toluene annual maximum concentration is 0.71µg/m^3, HI is 0.002. The location of the highest concentration is UTM coordinate (182,2504), which was the intersection of Fongshan City of Kaohsiung County and Kaohsiung City, near the Kaohsiung Interchange of #1 Highway.

Table 3. Maximum concentration and HI of modeled toluene

Source Type		Max. modeled Concentration (µg/m^3)	Max. HI
Stationary Source	Stack	95.8	0.24
	Fugitive	28. 9	0.072
On-road Mobile Source	Gasoline vehicle	11.5	0.029
	Motorcycle	4.4	0.011
	Diesel engine	0.7	0.002
	Average	16.6	0.042

HI= concentration /RfC Toluene：RfC = 400µg/m^3

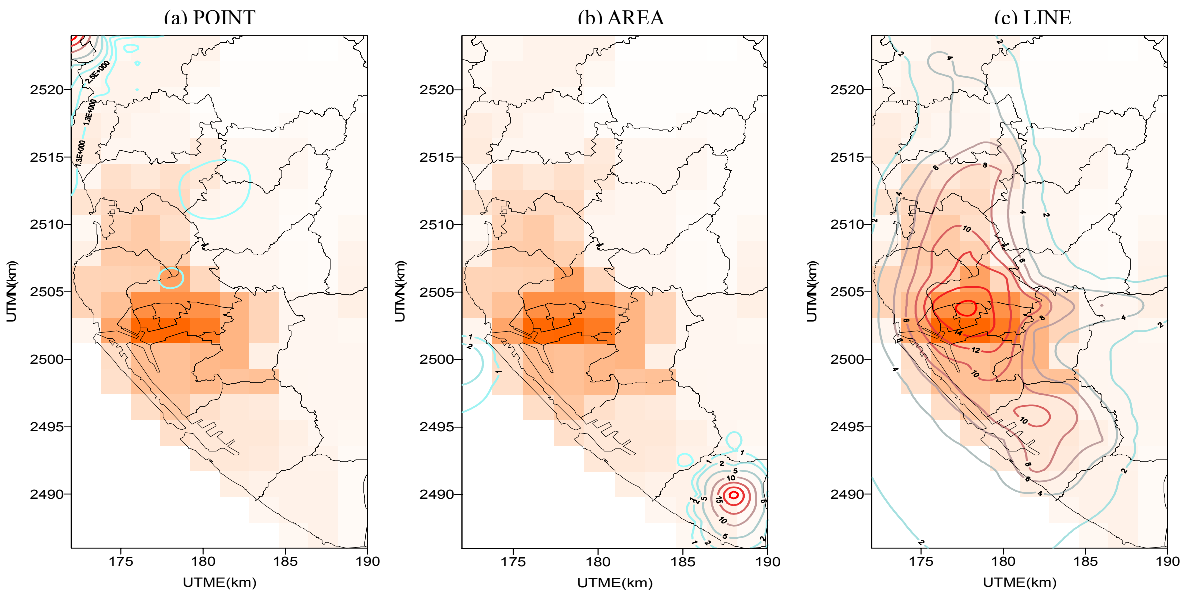

Fig.4.Toluene annual maximum concentration from (a) point, (b) area and (c) on-road mobile sources.

CONCLUSIONS

The risk of benzene (carcinogen) and toluene (non-carcinogen) were estimated from a stationary and mobile source in Kaohsiung area. Result of the cancer risk from stack and fugitive source were higher than target limit (10^{-6}). Cancer risk resulted by benzenes from on-road mobile sources also exceed target limit, and was higher than stationary source. Mobiles lead the potential impact to the public. That was significant to reduce benzene emission from mobile source. However, stationary source caused a significant impact in its vicinity and defined as a hot-spot. Toluene was selected as a non-cancer risk compound. Results indicated the hazardous index was less than 0.1 for both of stationary and mobile sources that were no significant healthy effect to people.

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