Evaluation of Human Health Risk due to Benzene Exposure in Japan

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Abstract

The distribution of individual cancer risk for lifetime due to exposure to benzene in the outdoor atmosphere was evaluated for the entire Japanese population of approximately 125 million people, using data on monitored ambient NOx levels at monitoring stations throughout the country and the regression equation between the levels of Benzene and NOx. Levels of NOx could be used as a surrogate for evaluating ambient benzene levels. Thus, ambient levels of benzene and population exposed to given levels of benzene were estimated throughout Japan. Then population exposed to given excess lifetime cancer risk was estimated, using the unit risk data of benzene. As a result, it was estimated that about 60% of the population was exposed to benzene levels above the Environmental Quality Standard Level of 3 μg m^{-3} (0.94ppb), corresponding to the excess lifetime cancer risk of 1×10^{-5}, for benzene in Japan.

1. Introduction

Benzene is a known human carcinogen according to epidemiological studies (Crump et al., 1984; IARC, 1982; Paustenbach et al., 1992, 1993; Paxton et al., 1994; Rinsky et al., 1987), and a causal agent of acute leukemia, especially acute myelogenous leukemia. The U.S. EPA classifies benzene as a Group A human carcinogen. Although ambient levels of benzene are much lower than levels of occupational exposure reported in epidemiological studies cited, long-term exposure to ambient levels of benzene may cause adverse human health effects.

In Japan, the Air Pollution Control Law was revised in May, 1996, and the Japan Environment Agency has undertaken to control environmentally hazardous air pollutants (HAPs). A total of 234 HAPs have been newly listed in addition to traditional pollutants such as NO_2, CO, SPMs, for which the levels of Environmental Quality Standard (EQS) had been

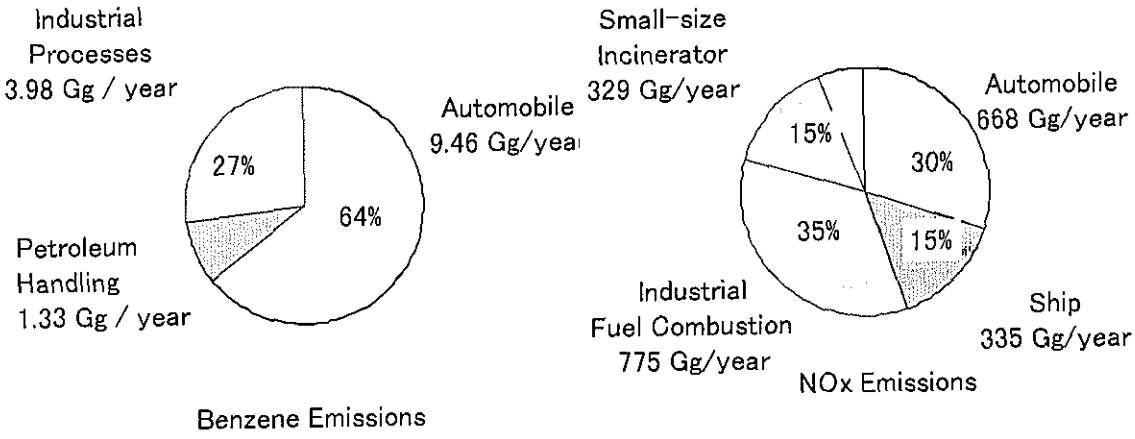

Fig. 1 Sources of Benzene and NOx Emissions. Benzene data from the Ministry of International Trade and Industry in Japan, 1995, and NOx data from the Japanese Environment Agency, 1994.

already set. Of 234 HAPs, 22 pollutants are suggested as priority chemicals of concern (the Japanese Environmental Agency, 1997). In February 1997, the level of the EQS of 3 μg m^{-3} for benzene was established.

Measuring benzene levels in Japan has begun, but at present benzene is not routinely monitored nationwide. Therefore, data are not sufficient for predicting the ambient levels and the risk due to benzene exposure throughout the country.

Fig. 1 shows sources of benzene and NOx emissions in Japan. The largest source of benzene emissions is automobiles (64%). Although the ratio of automobiles in NOx emissions accounts for 30%, emissions from automobiles would dominate ambient levels of NOx in residential areas, because NOx from other sources, far from residential areas in location and altitude, is diluted through diffusion. Thus, ambient levels of benzene and NOx are considered to be dominated by emissions from automobiles.

Levels of NOx are monitored at approximately 1800 monitoring stations nationwide. Therefore, if we can determine the relationship between levels of benzene and NOx, the NOx data would allow greater spatial resolution in evaluating ambient benzene levels and the cancer risk due to benzene exposure.

In this paper, the population distribution vs. benzene levels and that vs. cancer risk are evaluated.

2. Method

Ambient benzene and NOx levels were monitored hourly everyday from April to November, 1997 at the Institute of Environmental Science and Technology, Yokohama National University (YNU). Yokohama is a large city with a population of about 3 million, and the density of population is about 7,500 person/km^2, where the traffic is heavy. YNU is located on

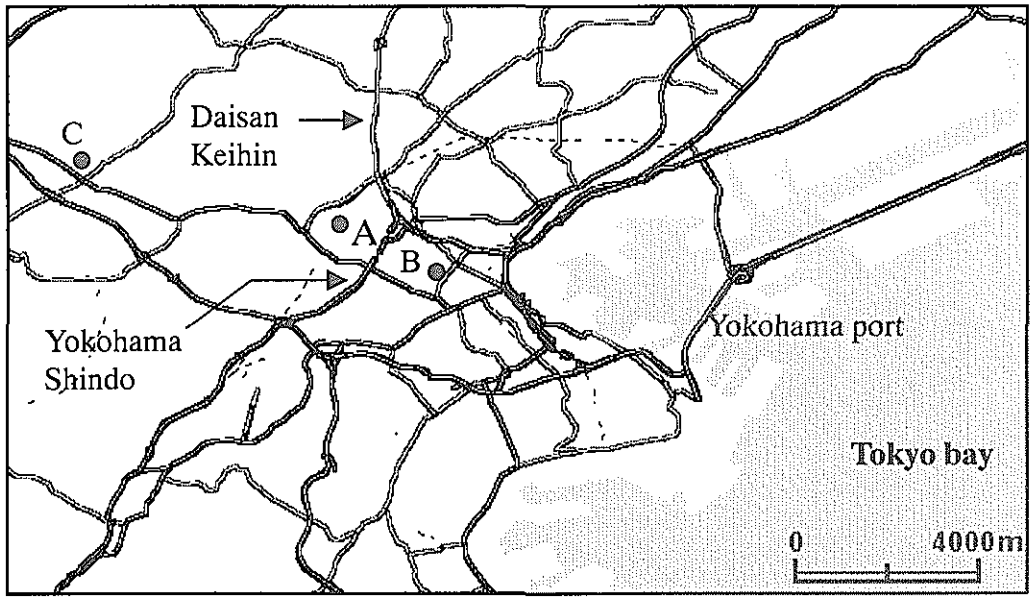

Fig. 2 A map of sampling points in Yokohama.
A: Yokohama National University, B: Sengen-shita crossing, C: Tsuoka Crossing.

a hill (altitude 40m) about 5km northwest of the central part of Yokohama (Fig. 2) close to a principal road (Yokohama shindo; traffic density approximately 50,000 cars/day). The monitoring point was on the 3rd or 4th floor of the institute located about 400m away from the road and to the northeast.

Benzene was analyzed and quantified by GC - FID (HP 6890) linked with an automatic gas concentrator (DKK GAS - 10). A purge and trap technique was used to concentrate the volatile chemicals. Ambient air was sampled at 60 ml / min for 10 min (total volume 600 ml) into a concentration tube filled with Tenax GC (60 / 80 mesh) as an adsorbent at 10 ℃. Chemicals were injected into the gas chromatogragh after thermal desorption at 250 ℃. They were separated by GS Alumina (0.53mm I.D., 30m length, J&W Co. ltd.) or DB - 1 (0.53mm I.D., 30m length, 5 μ m film thickness, J&W Co. ltd.), with the following oven temperature programs; GS Alumina: 40℃ for 3min → 20 ℃ / min → 160 ℃ → 2 ℃ / min → 200℃ →20 ℃ / min → 270 ℃ for 15 min, DB – 1: 35℃ for 5 min → 10 ℃ / min → 85℃ → 1℃ / min → 100℃ → 20℃ / min → 200℃ → 250℃.

NOx were monitored by ambient nitrogen oxide monitor (DKK GPH - 74M) using Saltzman method. Ambient levels of benzene and NOx were also monitored at 3 points (A, B, C in Fig. 2) in the autumn of 1996.

3. Results and Discussion

3.1 *Monitoring*

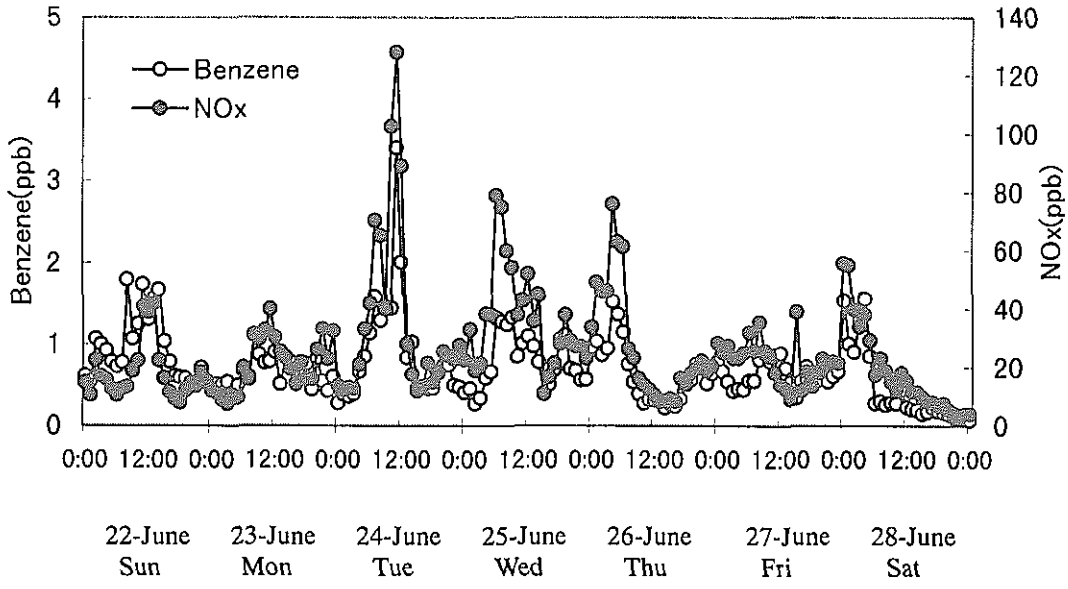

Fig. 3 Change over time in ambient benzene and NOx levels monitored at YNU, 1997.

Fig. 3 shows an example of hourly changes in ambient benzene and NOx levels. Although levels of benzene and NOx varied drastically over the course of one day, the both levels were highly correlated. Drastic changes in the levels did not seem to be related to the traffic density patterns.

The relationship between levels of the both chemicals and various meteorological factors such as temperature, humidity, wind speed, and wind direction was investigated. An inverse correlation was observed between concentration and wind speed; the concentration decreased when the wind speed increased, irrespective of wind direction. One explanation for this may be that the level around the ground is determined by the diffusion velocity of the gas emitted there. A clear correlation has not been found between levels and the other meteorological factors as well.

3.2 *Correlation*

The correlation between benzene and NOx levels was examined using the monitoring data collected from April 26 to July 5, 1997. The average levels of Benzene and NOx from April to July were 1.0ppb and 28.0ppb, respectively. Fig. 4 is the scatter plot of benzene (= y) and NOx (= x) concentrations, in which the axes were expressed in logarithmic form. Benzene concentration were assumed to be proportional to NOx concentration to simplify the model. Because both concentrations showed a log normal distribution, the relationship between log x and log y was examined.

$$\log y = \log x + A \qquad (1)$$

Substituting all the data into equation (1), average and standard deviation of A were determined. Regression analysis yielded the following equation,

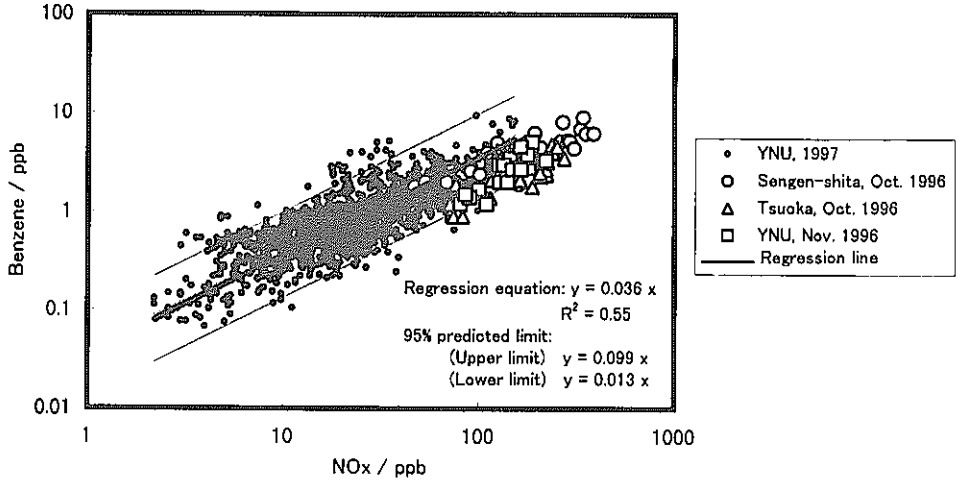

Fig. 4 Scatter Plot of benzene and NOx levels measured at YNU, Apr.- Jul., 1997.

$$y = 0.036\,x \tag{2}$$

A 95% confidence limit and a 95% predicted limit were also derived as follows

$$y = 10^{\mu_A \pm \sigma_A/\sqrt{n}}\,x \quad \cdots 95\%\ \text{confidence limit} \tag{3}$$

$$y = 10^{\mu_A \pm \sigma_A}\,x \quad \cdots 95\%\ \text{predicted limit} \tag{4}$$

where n is the number of samples, and μ_A, σ_A are the arithmetic average and the standard deviation for A, respectively. The 95% confidence upper limit was derived as 0.037x and lower limit was 0.035x. The 95% predicted upper limit was 0.099x and lower limit was 0.013x .

The coefficient of determination, R^2, was determined to be 0.55 (R = 0.74). Above all, a proportional relationship between benzene and NOx levels was obtained with relatively high correlation. The regression equation, y = 0.036 x, was used for the subsequent analyses.

Results of the monitoring in the autumn of 1996, are also plotted in Fig. 4. Almost all data are included in the 95% prediction limit.

3.3 *Exposure distribution*

Levels of NOx are monitored continuously at 376 Automobile Exhaust (AE) monitoring stations and 1443 General Air Pollution (GAP) monitoring stations nationwide. The AE monitoring stations are located close to principal roads, while the GAP monitoring stations are located away from principal roads and other emission sources. For each of the monitoring station, benzene level was estimated from annual average level of NOx (the Environment Agency: 1994) using the regression equation derived in 3.2.

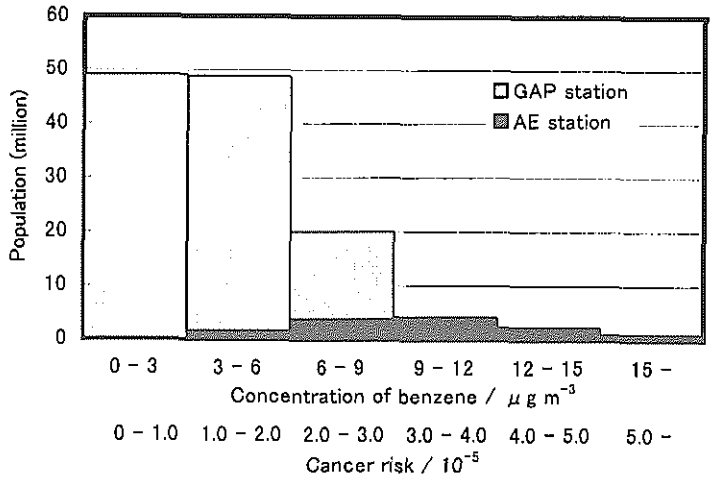

Fig. 5 Distribution of population vs. concentration of benzene and cancer risk.

The distribution of population and land area exposed to various levels of benzene was evaluated according to the following classification and assumption. The population and the land area were based on the Municipal Survey (the Management and Coordination Agency: 1995).

i) **URBAN** : defined as municipality which has both GAP monitoring stations and AE monitoring stations. About 80% of the population living in the municipality is exposed to benzene at the levels of GAP monitoring stations, and 20% of the population is exposed to the levels at AE monitoring stations.

ii) **SUBURB** : defined as municipality which has only GAP monitoring stations. The entire population living in the municipality is exposed to benzene at the levels of the GAP monitoring stations.

iii) **RURAL** : defined as municipality which has no monitoring stations. The entire population living in the municipality are exposed to benzene in the level at the GAP monitoring stations close to the municipalities.

Fig. 5 shows the distribution of the population vs. benzene concentrations. The population apparently followed log normal distribution pattern with slight tailing to the right. About 60% of the population was exposed to benzene at a level above the EQS level of 3 μg m^{-3}. The right side at a distribution may be the population living closest to the principal roads and directly affected by emissions from automobiles.

Fig. 6 shows the distribution of the land area in Japan versus benzene concentrations. About 80% of the land is below the EQS level for benzene, and 20% is above the EQS level. Consequently, 60% of the population was found to live in 20% of the area where the concentrations were above the EQS level. The areas with high population density reflect high levels of benzene.

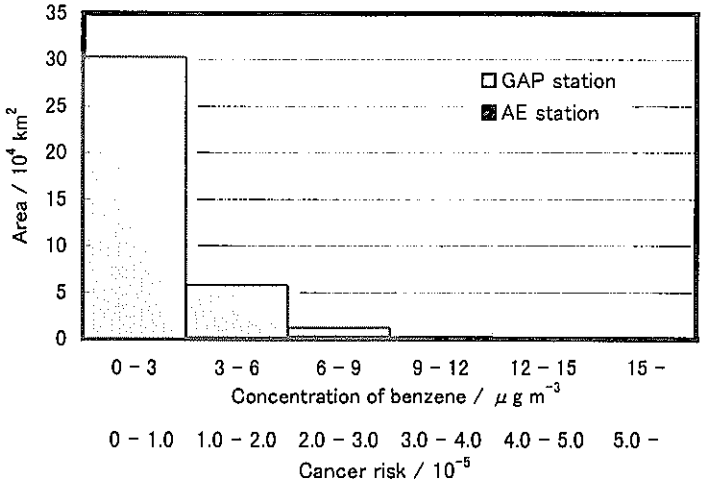

Fig. 6 Distribution of land area vs. concentration of benzene and cancer risk.

3.4 *Population Risk*

Fig. 5 shows the distribution of population versus excess lifetime cancer risk due to benzene exposure. Excess lifetime cancer risk was calculated using the unit risk of benzene. In this work, we used the value of $3\times10^{-6}\,\mu g^{-1}\,m^3$ as the unit risk proposed by Japanese Environment Agency, which might be unreasonable because this value was much smaller compared with other reported values, such as $8.1\times10^{-6}\,\mu g^{-1}\,m^3$ proposed by U.S. EPA.

The Japanese Environment Agency has proposed a level of 1×10^{-5} as the permissible maximum value for individual excess lifetime cancer risk, which was corresponding to the EQS level of $3\,\mu g\,m^{-3}$ as shown in Fig. 5. About 60% of population would be exposed to excess lifetime cancer risk over 1×10^{-5}. Aggregate population risk was calculated that the annual death due to exposure to benzene was 25 cases.

To reduce the cancer risk due to benzene equally throughout the country, reduction of ambient benzene level is indispensable. Efforts such as reduction of the amount of benzene contained in gasoline, or improvement of the conditions of combustion in engines, would be effective. The population ratio exposed to the ambient benzene level above the EQS level is expected to decrease when the ambient benzene level is reduced as shown in Fig. 7.

At the reduction ratio of 60%, only 10% of the population would live in the atmosphere with benzene level above the EQS. But over the reduction ratio of 60%, the population ratio exposed to the level above EQS would not decrease remarkably; in other words, uniform reduction over 60% would be inefficient. The ratio of 60% would be appropriate as the target value of reducing ambient benzene levels nationwide.

What is required to decrease the excess cancer risk in addition to the uniform reduction of ambient benzene level? At least, information about regions closest to principal roads exposed to high cancer risk should be open to the public. Such information could be a great help to avoid further exposure to high cancer risk.

For further study, more monitoring data over a longer term and data at other locations

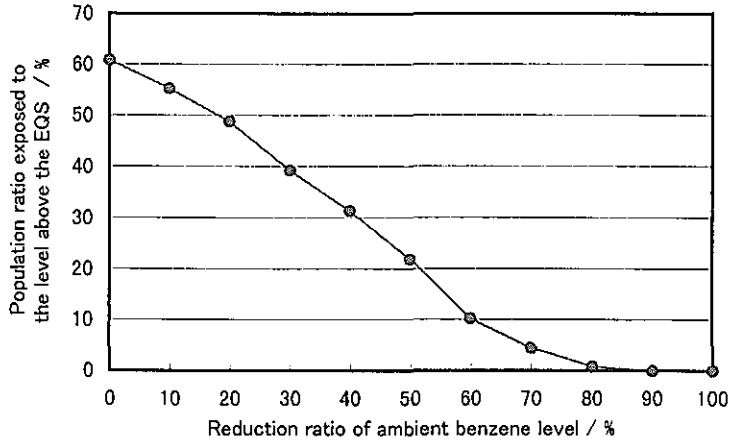

Fig. 7 Population ratio exposed to the level of benzene above the EQS level vs. reduction ratio of ambient benzene level.

are definitely needed to enhance the correlation between benzene and NOx and to examine the validity of NOx data as an indicator of benzene levels nationwide.

4. Acknowledgments

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