# Exposure assessment of benzene from vehicles in Japan

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**Abstract**

The population cancer risk due to benzene was evaluated for the entire Japanese population (P = 125 million). Data obtained in monitoring of ambient NOx levels were used for prediction of the nationwide benzene exposure levels. The regression equation obtained for NOx levels (X in ppb) and benzene levels (Y in $\mu g/m^3$) was $Y = 0.181 X^{0.806}$ with the coefficient of determination $R^2 = 0.73$. This result indicates that ambient NOx monitoring data can be used for reliable prediction of ambient benzene level.

In Japan, NOx levels in the ambient environment have been precisely monitored and their hourly average values have been recorded at 1461 general air pollution monitoring stations (GAP) nationwide and at 382 automobile exhaust monitoring stations (AE) adjacent to major roads. Exposure analysis was performed for the roadside population and for the general environment population, the exposure level for the former was calculated based on the data from the AE monitoring stations and exposure levels for the latter was calculated based on the data from the GAP monitoring stations.

The distribution of excess cancer risk due to exposure to benzene from vehicles was established based on the EPA cancer unit risk. Our results indicated that about 75 percent of the entire population was exposed to a lifetime cancer risk level of $1 \times 10^{-5}$ or greater, and the excess lifetime cancer risk due to one-year-exposure to benzene (Annual Risk) was estimated to be 27 cases.

The benzene content in gasoline will be reduced from the current level of 2.3 vol %, to less than 1 vol % by the end of 1999 in accordance with the guidelines of the Japan Central Environment Council. When this goal is achieved, the total risk due to ambient benzene exposure is estimated to decrease by 27%. The annual risk is expected to be reduced by 7.3 cases through regulation of gasoline.

For reduction of the benzene content in gasoline, the initial cost of 100 billion yen for plant and equipment investment, was converted to an annual cost, which was added to the running cost of 13 billion yen per year to produce a total annual cost of 20 billion yen. The cost per life saved by regulation of gasoline is estimated to be 2.7 billion yen.

## 1. Introduction

Benzene is an aromatic volatile organic compound (VOC) characterized by the U.S. Environmental Protection Agency as a "known" human carcinogen for all routes of exposure based upon convincing human evidence as well as supporting evidence from animal studies. (U.S. EPA, 1998).

In Japan, assessments of the human health risk due to exposure to ambient benzene are limited by the paucity of available data on benzene levels because benzene levels are not routinely monitored in many locations throughout Japan. (Miura et. al. 1991, Uchiyama et. al. 1991, Nakanishi 1995, The Japan Central Environment Council 1996) An alternative approach to determining ambient benzene levels is to relate its levels with those of another chemical species for which sufficient data are available (Macintosh 1995).

The major source of benzene in the atmosphere is emissions from automobiles, which is also one of the primary sources of nitrogen oxides (NOx). NOx levels are measured every hour on average at numerous monitoring stations across the country. Therefore, the use of NOx as a surrogate for benzene would allow for greater spatial resolution in the assessment of benzene exposure if we know the relationship between ambient NOx and benzene levels.

## 2. Population distribution exposed to ambient NOx

Levels of ambient NOx are monitored continuously at 376 Automobile Exhaust (AE) monitoring stations and at 1443 General Air Pollution (GAP) monitoring stations throughout Japan. 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. The distribution of the population exposed to various levels of NOx was evaluated according to the following classification scheme. The population size was based on the results of the Municipal Survey (Japan Management and Coordination Agency, 1995).

i ) **URBAN** : defined as a municipality which has both GAP monitoring stations and AE monitoring stations. Ten percent of the population was assumed to live at a "roadside" exposed to the NOx levels measured at the AE monitoring stations set in the municipality, and 90 percent of the population living in the municipality was assumed to be exposed to the NOx levels measured at the GAP monitoring stations set in the municipality.

ii ) **SUBURB** : defined as a municipality which has only GAP monitoring stations. The entire population living in the municipality was assumed to be exposed to the NOx levels measured at the GAP monitoring stations set in the municipality.

iii) **RURAL** : defined as a municipality which has no monitoring stations. The entire population living in the municipality was assumed to be exposed to the same NOx levels as those at the GAP monitoring stations close to the municipality.

The term "roadside" referred to above was defined as the land area within 30 meter of the edge of a principal road. The 30 meter distance, which represents the limit to which heavy emissions extend from an automobile running on a principal road, was derived using a pollutant fate model simulation. The assumption that 10 % of the population lives at the roadside and the remaining 90 % of the population lives in the general environment was based on data in the Roadside Noise Report by Japan Environment Agency (JEA) in 1990. The size of the roadside population was estimated to be 6 million, which accounts for 5 % of the total population.

Fig. 1 provides the histogram of exposed NOx levels by the Japan population. The NOx levels exposed by the roadside population and the general environment population were shown in section 5. The NOx levels exposed to roadside population were 3 times higher than NOx levels exposed to general environment population.

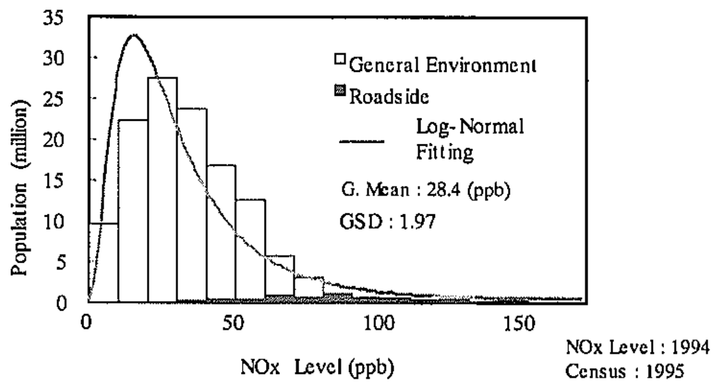


Fig. 1 A histogram of the NOx levels to which the Japanese population is exposed.

## 3. Monitoring and correlation analysis

The ambient benzene and NOx levels for correlation analysis were monitored from May, 1997 to October, 1998 at the Institute of Environmental Science and Technology located on the campus of Yokohama National University (YNU) in Yokohama city. Yokohama city is a municipality belonging to category i) URBAN according to the classification scheme in section 2. The monitoring point was a general environment since the nearest principal road is 400 meter away. The detailed information about experimental apparatus and measuring condition was provided in the previous study (Kajihara et al, 1998).

The time course of change in benzene and NOx levels through a one-year period are shown in Fig. 2. The levels of both pollutants showed similar seasonal trends in that the levels in winter were higher than those in summer. Pollutant levels were not measured during period from August to October 1997 because of trouble with the apparatus.

Table 1 Statistical parameter of measured data

| | NOx | Benzene |
|---|---|---|
| Number of Data | 407 | 407 |
| Average | 41.3(ppb) | 3.67 ($\mu g/m^3$) |
| Standard Deviation | 28.3(ppb) | 2.20 ($\mu g/m^3$) |
| Geometric Mean | 33.3(ppb) | 3.06 ($\mu g/m^3$) |
| Geometric Standard Deviation | 1.96 | 1.88 |

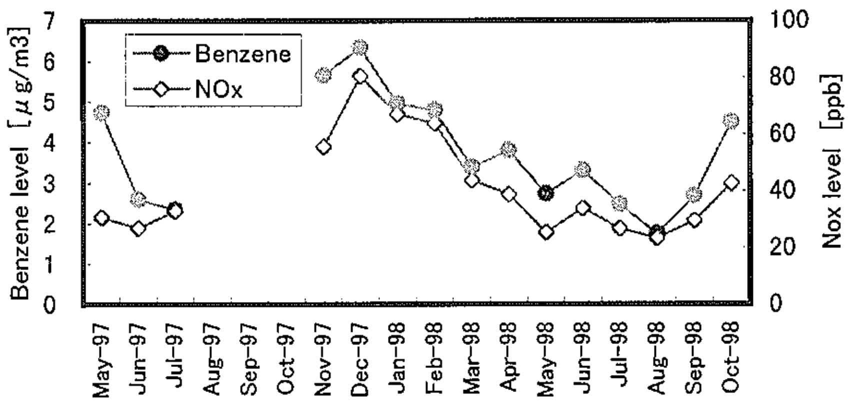


Fig. 2 Comparison between seasonal trends of the levels of Benzene and NOx monitored at YNU.

The 24-hour average benzene and NOx data sets were used for correlation analysis, and the parameter values are listed in Table 2. In Fig. 3, scatter plots of the 24-hour average benzene and NOx levels are shown with histograms for both agents. Since the data for both benzene and NOx levels were found to be approximately log-normally distributed, the correlation between the logarithm of benzene concentration and the logarithm of NOx concentration was examined. The following linear regression equation was obtained with a high correlation coefficient ($R^2 = 0.73$)

$$Y = 0.8058\,X - 0.7415 \qquad (1)$$

Here, X is the logarithm of the NOx concentration in ppb and Y is the logarithm of the benzene concentration in $\mu g/m^3$. Eqn. (1) can be converted to the equation,

$$[\text{Benzene}] = 0.1814\,[\text{NOx}]^{0.8058} \qquad (2)$$

Here, [Benzene] and [NOx] represent the concentration of each agent, benzene in $\mu g/m^3$ and NOx in ppb. The regression line corresponding to Eqn. (2) is shown in Fig. 3. Since Eqn. (2) was obtained using data measured at only one monitoring point, the outputs of the Eqn. (2) were compared to the monitoring data measured at several points in order to confirm the validity of

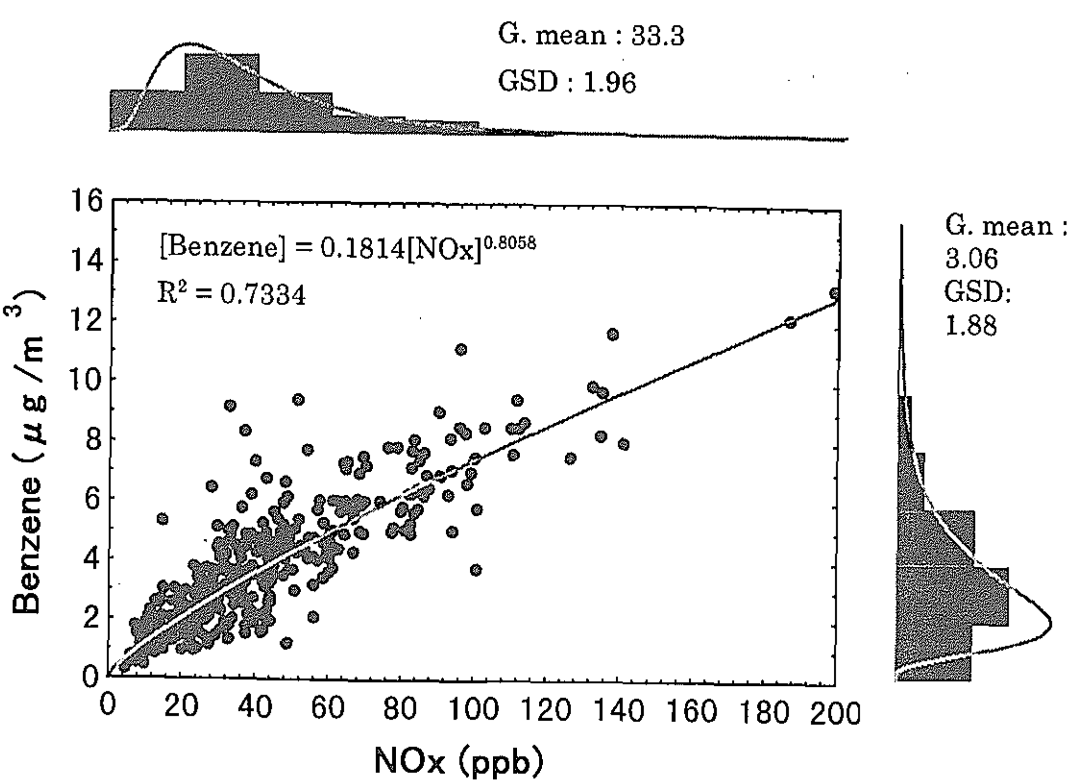


Fig. 3 Scatter plot and histograms of measured benzene and NOx levels measured at YNU.

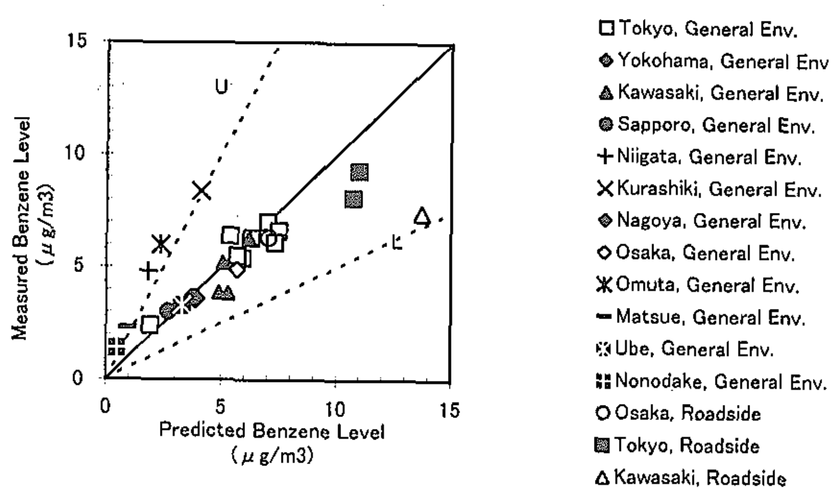


Fig. 4 Comparison between measured and predicted levels of benzene

U : 95% upper prediction limit
L : 95% lower prediction limit
The sources of measured data were offered from National Institute for Environmental Studies, The Air Quality Bureau of the Japan Environment Agency, Tokyo Metropolitan and Kawasaki city

Scatter plots of ambient benzene and NOx levels measured at about ten monitoring points throughout Japan (JEA 1996) together with the regression line and prediction limit lines are shown in Fig. 4. Since most of the data were included within the 95 % prediction interval, it was judged that the benzene levels were predicted reasonably well using regression Eqn. (2).

## 4. Estimation of aggregated population risk due to exposure to benzene in Japan

The levels of exposure to benzene were calculated using Eqn. (2) by substituting the annual average NOx levels for each of the municipalities (JEA, 1994) into regression equation (2) obtained in the preceding section. About 47 % of the total population was exposed to benzene at a level above the Environmental Quality Standard level of 3 $\mu$g / $m^3$. The population weighted average levels of exposure to benzene estimated for the roadside population, the general environment population and the total population exposed are shown in Table 2. The Predicted level of exposure to benzene for the roadside population was estimated to be about 2.3 times higher than that in the case of the general environment population.

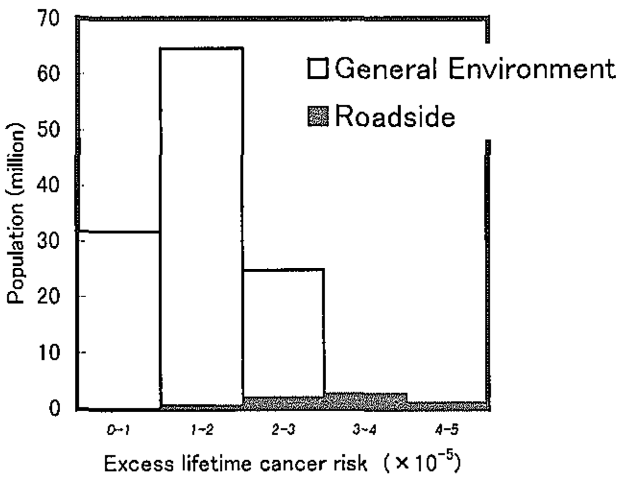


Fig. 5 Histogram of the excess lifetime cancer risk due to ambient exposure to benzene

Fig. 5 is a histogram of the excess lifetime cancer risk suffered by the Japanese population due to exposure to ambient benzene. The excess lifetime cancer risk is the product of the level of exposure benzene ($\mu g/m^3$) and the unit risk ($m^3/\mu g$) for benzene. The unit risk for benzene was set at 5 x $10^{-6}$ $m^3/\mu g$ in this report by referring the range of 2.2 x $10^{-6}$ - 7.8 x $10^{-6}$ $m^3/\mu g$ reported by the U.S. EPA in 1998. About 75% of the population would be exposed to an excess lifetime cancer risk greater than $1 \times 10^{-5}$, which is the risk value proposed by the JEA as the permissible maximum value for individual excess lifetime cancer risk.

The population aggregated excess lifetime cancer risks in Japan were estimated based on the following calculations. The predicted level of benzene exposure for each municipality or part of a municipality (roadside area or general environment area) was multiplied by the unit risk for benzene and multiplied by the population of the municipality or part of a municipality. The sum of the population risk for each municipality or part of a municipality, $i$, represents the aggregated population risk in Japan.

$$R = U\sum_i B_i P_i \qquad (3)$$

where $R$ is the aggregate population excess cancer risk from lifetime exposure to benzene, $U$ is the unit risk for benzene, $B_i$ is the predicted benzene level in the municipality or part of a municipality, $i$, and $P_i$ is the population of $i$.

Table 2 Population, NOx exposure level, predicted benzene exposure level, aggregate population excess cancer risk from lifetime exposure to benzene and annual population risk in Japan

| Area | Population (million) | NOx Exposure Level (ppb) *1 | Benzene Exposure Level ($\mu g/m^3$) *1 | Aggregate Population Risk (cases) | Annual Risk (cases) |
|---|---|---|---|---|---|
| Roadside | 6.4 | 86.6 | 6.54 | 209 | 3.0 |
| General | 119 | 31.9 | 2.88 | 1716 | 24.5 |
| Total | 125 | 34.6 | 3.07 | 1925 | 27.5 |

*1 Population weighted arithmetic mean value

The aggregate population excess cancer risk from lifetime exposure to ambient benzene for the roadside population, that for the general environment population and that for the total population are shown in Table 2. When the average lifetime of members of the Japanese population is assumed to be 70 years, the annual risk, which is the population aggregated excess lifetime cancer risk due to one-year-exposure to benzene, was estimated to be 27.5 cases in Japan as shown in Table 2.

## 5. Estimation of risk reduction and cost for countermeasure to gasoline

The Japan Central Environment Council has proposed that the permissible limit for benzene content in gasoline should be reduced to 1 vol. % from the current level of 5 vol. % by the end of 1999 as indicated in the report submitted in October, 1996.

The detail of benzene discharge was shown in Table 3. If benzene content would be changed from the average level of 2.3 volume % reported in 1996 to the average level of 0.7 volume % by the regulation that the upper limit of benzene content level in gasoline must be 1 vol. %, total benzene discharge per year would be estimated to decrease from 18400 ton to 13505 ton as shown in Table 3. The decrease would be 4895 ton/year which should mean that total benzene discharge would reduce 27%.

If the ambient benzene levels are assumed to decrease in proportion to the change in benzene discharge, the population aggregated excess lifetime cancer risk due to ambient exposure to benzene would also decrease by 27%. Eventually, annual risk would be expected to decrease 7.3 cases per year.

The total initial cost for plant and equipment investment to reduce the benzene content in gasoline was estimated by the Petroleum Council (Petroleum Council, 1996) to be 95.7 - 100.5 billion yen. In this study, the total initial cost for plant and equipment investment was supposed to be 100 billion yen, which was converted to an annual capital cost of 7.0 billion yen based on the assumption that the discount rate is 0.05 and the period of depreciation is 25 years. The running cost was estimated by the Petroleum Council to be 13 billion yen per year. Consequently, the annual cost was estimated to be 20 billion yen which is the sum of the annual capital cost of 7.0 billion yen and the running cost of 13 billion yen. Since it costs 20 billion yen per year to reduce 7.3 cases of the annual risk, the cost per one life saved by countermeasure involving changes to gasoline was estimated to be 2.7 billion yen.

Table 3 The effect of regulation to gasoline to benzene emission

| Emission Source | Emission (ton/year) Before Act [*1] | After Act | Reduction Ratio |
|---|---|---|---|
| Automobile | 13200 | 9240 | −30% |
| Gasoline Tank and Station | 1200 | 365 | −70% |
| Chemical Industry | 3800 | 3800 | 0 |
| Coke Oven Gas | 100 | 100 | 0 |
| Total | 18400 | 13505 | −27% |

[*1] Japan Central Environment Council

## 6. Acknowledgments

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