

History of Yokkaichi Asthma and Its Anti-pollution Measures

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Abstract: In the initial period after the first petrochemical complex was built in the 1950s, air pollution was extremely high. As no significant prevention investments were undertaken, the damage was great. Since then, a considerable effort of investment has been made, and the damage has decreased markedly. The combined sum of investment plus damage cost can be regarded as the social cost caused by pollution. In this study, we seek essentially for the degree of pollution at which this social cost is minimized. With this view, a simulation model is used to represent the actual conditions existing in Yokkaichi in the past.

Key words: Air pollution, sulfur dioxide, Yokkaichi asthma, environment policy and investment, diffusion simulation.

1. Introduction

Industrialization and urbanization are currently proceeding at a rapid pace in many parts of the world, at the same time giving rise to problems of air and water pollution. Therefore, in order to conserve the earth's environment, more priority must be given to environmental investment, rather than to productive efficiency alone.

The facts presented in the other studies demonstrate the desirability of anti-pollution measures, assuming the costs incurred by the worst levels of atmospheric pollution previously experienced in Japan, especially in Yokkaichi.

In the initial period that petrochemical complex was built, air pollution damage was extremely high. Since then, a considerable effort of investment by Yokkaichi enterprises has been made, and the damage has decreased rapidly.

This study uses time series data for sulfur oxides (SO_x) levels in the atmosphere in order to trace the environmental facility investment costs by Yokkaichi

enterprises, and the resulting atmospheric recovery and decrease in compensation costs. Then a simulation model is used to investigate what the effect on damage costs would be of varying the amount and rate of environmental investment. In this way, it becomes possible to estimate the tradeoff between pollution damage and the pollution prevention investments made by petrochemical firms in Yokkaichi, as seen in the degree of air pollution.

2. Chronology of Yokkaichi Asthma in Japan

1941 Operations commence at Japanese Navy Fueling Depot (No. 2).

1945 World War II ended.

After the War:

1955 MITI & Cabinet (Government) adopted the Petrochemical Growth Action.

MITI transferred Navy Fueling Depot (No.2) to the private sector.

1959 The Petrochemical Complex No. 1 (Shiohama area) was fired up and (oil refining & power generation) the biggest complex in East Asia installed.

1960 Trouble of foul smelling fish from Yokkaichi waters (Ise Bay).

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1962 The Smoke and Soot Regulation Law (in government) was put into effect.

1962 Yokkaichi announced that SO_2 levels were higher, especially in Isozu (fisherman's town).

1963 The Petrochemical Complex No. 2 (Umaokoshi area) was fired up (full swing operation).

1964 Prof. Yoshida at Mie Univ. announced the correlation between SO_2 and asthma patients.

Mr. Furukawa (of 1st victim) at Shiohama (nearby Complex No. 1) died for pulmonary emphysema (Fig. 1).

1965 Yokkaichi city started public-paid medical care for victims (18 persons at first).

(In 12 persons lived at Isozu) (Japan's first free medical care system up to 1981)

1966 Mr. Kihira (75 years old) of the pollution designated victim committed air-dance suicide for asthma and economic distress.

1966 Mie Prefecture began telemetric monitoring of air pollution in Yokkaichi area.

1967 The 9 persons (suffering from asthma) filed a lawsuit against 6 petrochemical companies.

Mie Prefecture enacted the Environmental Pollution Prevention Ordinance.

1968 The Air Pollution Control Law was put into effect.

K-Value Regulation (K stands for ground concentration) for SO_2 emissions was put into use.

=> Higher smokestacks in petrochemical companies

1969 The Law for the Relief of Pollution-related Patients was put into effect.

1970 Public-paid medical care began under the law for the relief of pollution-related patients.

1971 Japan established the Environmental Agency.

1972 The Petrochemical Complex No. 3 (Kasumi-area) was fired up (full swing operation).

Mie Prefecture enforced the Environmental Pollution Prevention Ordinance.

Making the 1st time in Japan Total Emission Control is placed on overall SO_x in Yokkaichi.

The Tsu Court of Yokkaichi orders compensation

can be paid to sufferers of pollution related disease for 6 petrochemical companies.

=> TEC leads to introducing exhaust gas desulfurizer at the factories in Yokkaichi.

1973 The Pollution-related Health Damage Compensation Law was put into effect.

1974 Mitsubishi, Ishihara companies built desulfurizers based on lime-gypsum method reducing overall SO_x in boiler exhaust gas at its Yokkaichi plants.

1976 Mie Prefecture announced a cutback program on overall SO_x emissions in Yokkaichi.

1976 The environmental target value under 0.017 ppm per year for SO_2 was achieved determined from monitoring results in the whole Yokkaichi stations (Fig. 2).

Bronchial Asthma by Age Bracket in Yokkaichi (1960)

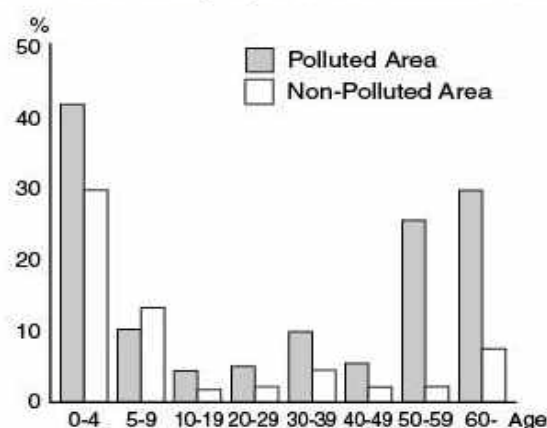


Fig. 1 High incidence in elder citizens.

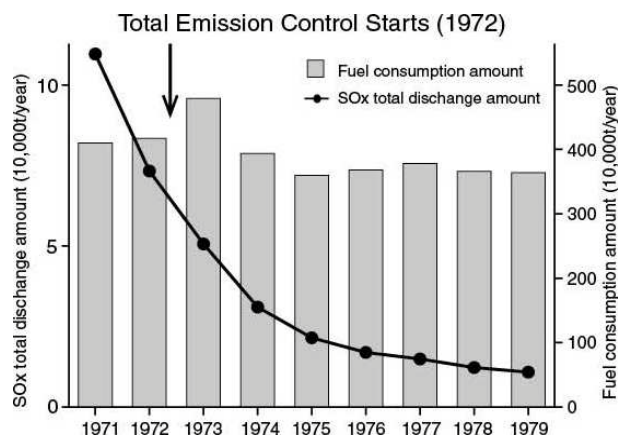


Fig. 2 Yokkaichi attains environmental standard (under 0.017 ppm per year for SO_2).

3. Yokkaichi Pollution and Environmental Policy

Yokkaichi is situated approximately in the center of Japan, nearby Nagoya city, and is known for its high concentration of petrochemical complexes. Soon after the first complex started operation in 1956, with full-scale operation in 1959, high incidences of respiratory diseases including bronchus asthma (generally known as Yokkaichi asthma in Japan) were found among the local residents in the areas (mainly in Shiohama and Isozu districts in Fig. 3) around the complex and this became a crucial social issue. What caused the diseases? It was atmospheric pollution through dust, evil-smelling smoke and sulfur oxides exhausted from smokestacks in many companies.

In accordance with the results of the measurement of sulfur oxides concentration in Isozu district for 2 years from November 1962 to October 1964 (for ex. in Fig. 4 and Table 1), the average value was found to be eight times higher than that of unaffected areas. In 1964, when a survey was initiated, the hourly maximum value of 1.64 ppm was recorded which is approximately 16 times higher than the value of the current hourly environmental quality maximum standard of 0.1 ppm.

Fig. 4 shows historical changes in the type of fuel and environmental equipment used by the city's petrochemical companies as well as other conditions affecting operations.

Following the World War, the Japanese economy gave priority to economic growth and, in accordance with national policy of the time, pursued development centered on key industries, such as heavy chemicals and automobiles. Construction on the country's first large scale petrochemical complex started in Yokkaichi in 1956 and full-scale operation began in 1959. But as a result of these activities, numerous local problems occurred, including atmospheric pollution through dust, evil-smelling smoke and sulfur oxides, and water pollution through oil discharge leading to contaminated fish.

The environmental restoration in Japan started in earnest when the "Smoke and Soot Regulation Law" was enacted in 1962. Before this law was passed, environmental pollution had become a social problem in the Yokkaichi area. From about 1960, the city systematically started measuring concentrations of air contaminants and performed health examinations on inhabitants. Also, it decided to pay patients' pollution-related medical costs.

In 1962, Yokkaichi set out emission standards, preparations for a system of environmental measurements and monitoring, and measures for monitoring the health of local inhabitants. And at the same time, Yokkaichi planned for the separation of petrochemical works and residential districts. The city established the green buffer belts between petrochemical area and residential area, and pursued other town planning expedients.

In petrochemical companies, steps were taken to ensure the diffusion of waste gases by means of high chimneys.

As the environmental problems worsened, a system of regulations for ground level concentrations of sulfur dioxide (K-values*) was established in 1969. Then regulations for total discharge amounts (total emission control) were introduced in 1972, setting a precedent for Japan as a whole. Moves were also made to decrease the sulfur content of fuel, and install waste gas desulfurization equipment.

* "K" stands for "Kankyo Kijun (in Japanese)" = environmental standards.

The Tsu Court of Yokkaichi ordered compensation had been paid to sufferers of pollution related disease for 6 petrochemical companies in 1972. Further, corporations which caused pollution were obliged to pay the medical costs and other living expenses of pollution victims. By the "Pollution-related Health Damage Compensation Law" enacted in 1974, the payment of compensation for damages and income loss to certified victims was made a duty.

Subsequently, after a series of trial and error actions,

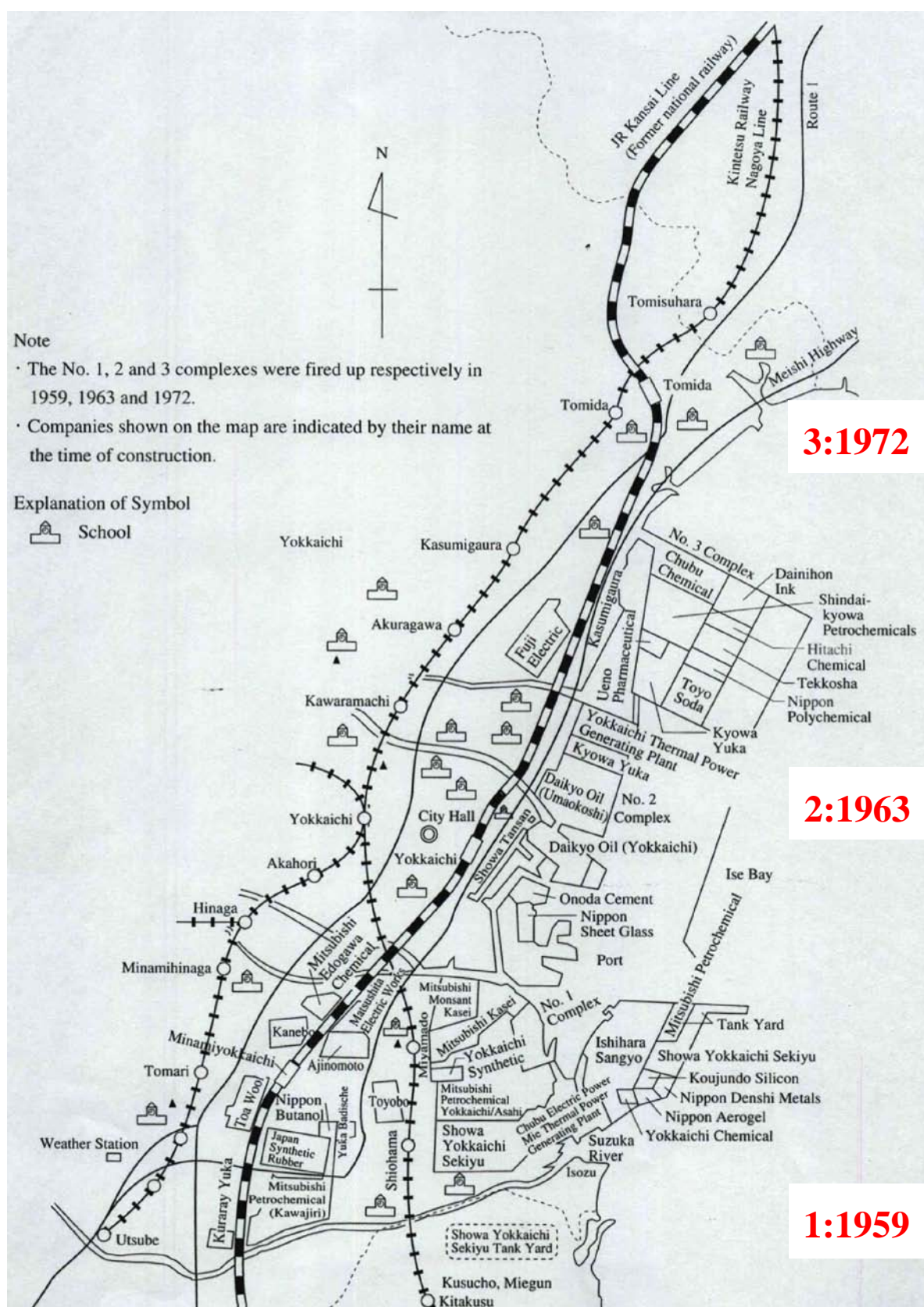


Fig. 3 Industrial map in Yokkaichi at the time of petrochemical complex construction.

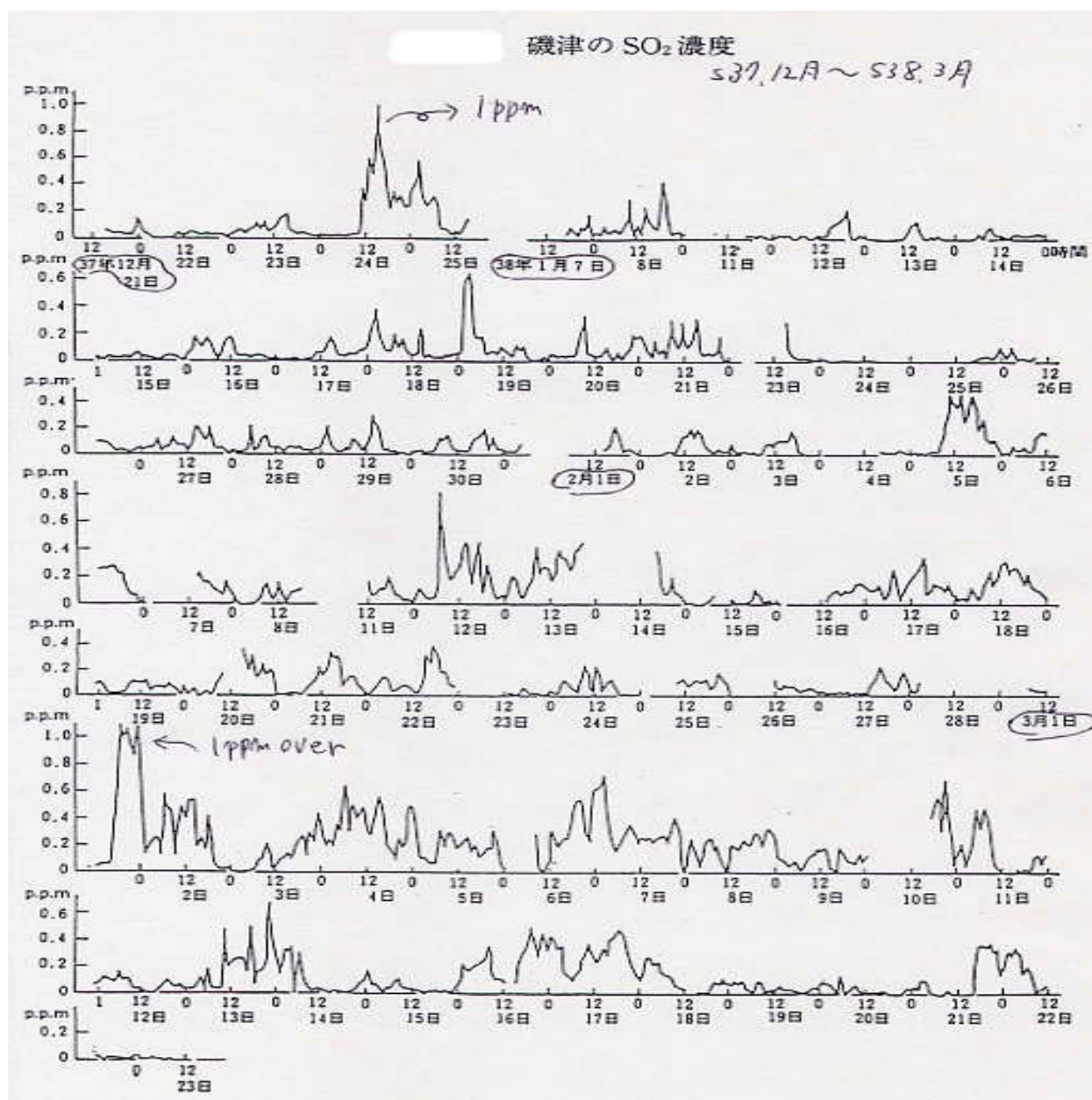


Fig.4 Data of SO₂ concentration (ppm) in Isozu from Dec. 1962 to March 1963.

Table 1 Historical changes in Yokkaichi for various kinds of items.

Items	1965	1975	1985	1995
Fuel, basic resources	Charcoal	Petroleum/low-sulfur petroleum	Natural gas	
Sulfur dioxide(SO ₂) concentration in the air	0.067 ppm	0.01	0.007	0.006
Environmental equipment	Dust collecting apparatus (-67)	High chimneys (66-77)	Desulfurizers (72-)	Nitrogen extractors
Environmental regulations	Dust regulations	K-value regulations (68)	Comprehensive regulations (72)	
National situation		Oil shocks (73, 79)	Rising yen rate recessions (77, 87)	

and efforts by the local administration, industry and the public, a notable improvement was achieved in the

condition of the city's air and water environment.

In 1990, the ICETT (International Center for

Environmental Technology Transfer) was founded in Yokkaichi in order to transfer the technological fruits of Japan's pollution experiences to other countries.

It is currently active in providing technological aid and cooperation to developing countries with environmental problems.

4. Diffusion Simulation for Sulfur Dioxide Concentration in Yokkaichi in the Past

In the case of Yokkaichi city that has large hills and mountains, it will be enough in analysis which used an atmospheric computational model by using the boundary-fitted coordinate system.

Therefore, we developed a computer program GGQuick 3D Diff. version that solves wind velocity calculation phase and diffusion process calculation phase alternately in time marching scheme [1]. GGQuick means the grid-generation curvilinear coordinate method with third-ordered upwind Quick convective terms for incompressible flow solver [2].

U is expressed as three components (u, v, w), and concentration of pollutant is expressed as c, you can solve the following time-dependent partial differential equation using the finite difference method for a three-dimensional field. Equations for convection and diffusion using Cartesian coordinates are as follows:

$$C_t + uC_x + vC_y + wC_z = (K_H C_x)_x + (K_H C_y)_y + (K_V C_z)_z + Q \quad (1)$$

Here K_H is the horizontal diffusion coefficient, K_V is the vertical diffusion coefficient, and Q is the amount of pollutants produced per unit time. Converted to a generalized coordinates system, these are:

$$\begin{aligned} (JC)_t + (JuC)_\xi + (JvC)_\eta + (JwC)_\zeta = & K_H ((Jg_1 C_\xi + Jg_2 C_\eta + Jg_3 C_\zeta)_\xi) \\ & + K_H ((Jg_2 C_\xi + Jg_4 C_\eta + Jg_5 C_\zeta)_\eta) \\ & + K_H ((Jg_3 C_\xi + Jg_5 C_\eta + Jg_6 C_\zeta)_\zeta) \\ & + K_V ((Jh_1 C_\xi + Jh_2 C_\eta + Jh_3 C_\zeta)_\xi) \\ & + K_V ((Jh_2 C_\xi + Jh_4 C_\eta + Jh_5 C_\zeta)_\eta) \\ & + K_V ((Jh_3 C_\xi + Jh_5 C_\eta + Jh_6 C_\zeta)_\zeta) \end{aligned} \quad (2)$$

where,

$$\begin{aligned} g_1 &= \xi_x^2 + \xi_z^2, g_2 = \xi_x \eta_x + \xi_z \eta_z, \\ g_3 &= \xi_x \zeta_x + \xi_z \zeta_z, g_4 = \eta_x^2 + \eta_z^2, \\ g_5 &= \eta_x \zeta_x + \eta_z \zeta_z, g_6 = \zeta_x^2 + \zeta_z^2, \\ h_1 &= \xi_y^2, h_2 = \xi_y \eta_y, h_3 = \xi_y \zeta_y, \\ h_4 &= \eta_y^2, h_5 = \eta_y \zeta_y, h_6 = \zeta_y^2. \end{aligned}$$

The equation may be developed by finite difference formulation at the all mesh points of the generalized coordinates and solved by computer. The Jacobian of coordinate transformation is J , where $J = \partial(x, y, z)/\partial(\xi, \eta, \zeta)$.

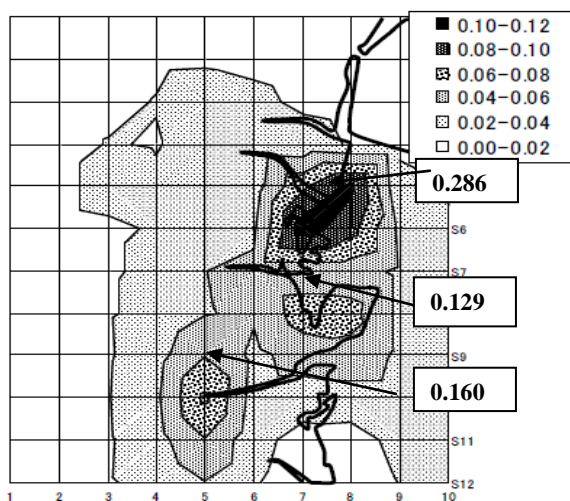
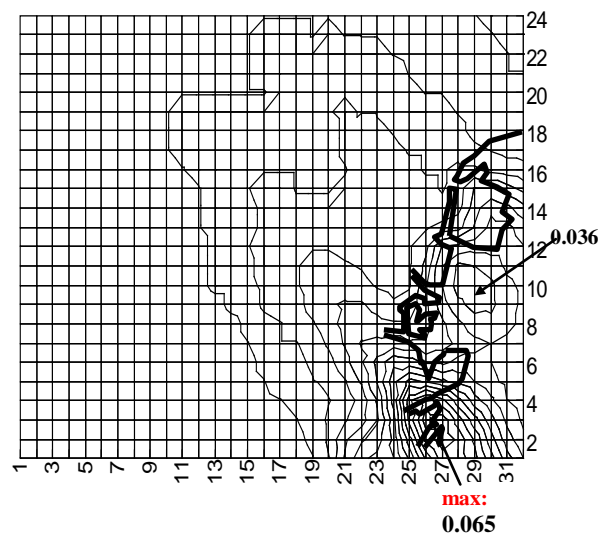
We estimated a simple year average in Figs. 6a and 6b using past smoke source data by figuring the weighted average by frequency of the several wind direction cases in 1967 and 1972 [3, 4].

We compared our year averaged concentration to computational result with the calculations of the Mie Prefecture project team of 1972 and with concentration measured by the Initiative for Reducing Total Emission of Sulfur Oxide Volume in 1971. Generally speaking, the present calculation results using a generalized coordinates system are reasonable and more favorable than those other using Cartesian coordinate models. Our computing results have good coincidence with sulfur oxides concentration measured by observation sites (Fig. 7).

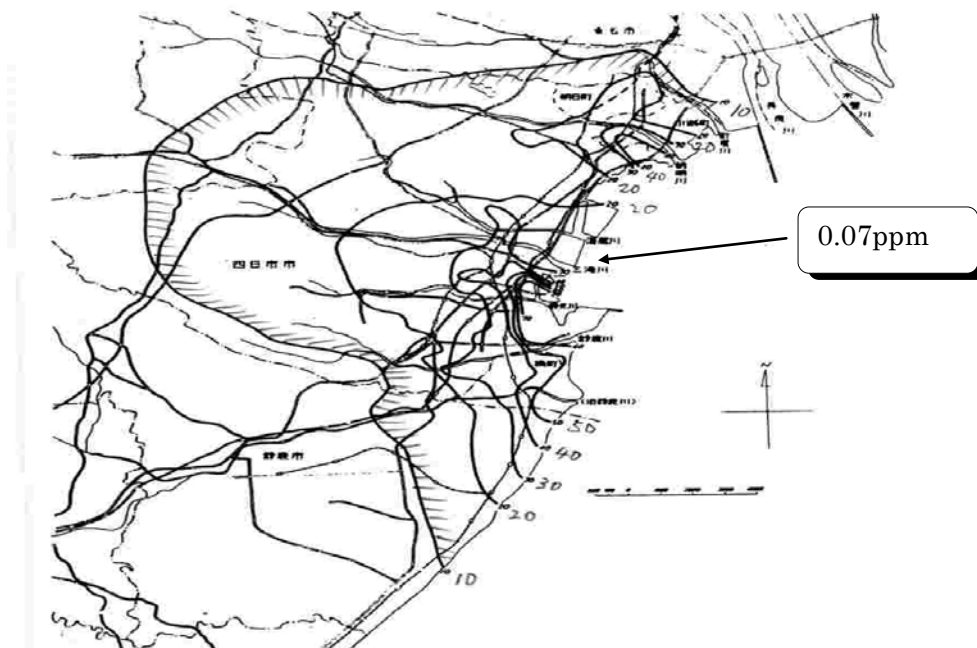
Because the smoke stacks of petrochemical companies were very low in 1967, the pollution area of high concentration appeared locally in some places and maximum value was yearly averaged 0.286 ppm along the coastal area of No. 2 petrochemical complex (Fig. 6a) [5]. If these conditions extremely continued, many asthma patients would occur in the future.

In Yokkaichi, total emission data of SO_2 was about 230,000 ton (= maximum value) per year in 1967 in Figs. 8a and 8c, and about 70,000 ton per year in 1972. Nowadays, around 3,000 ton per year was estimated to the air.

In 1976, concentration data of SO_2 was observed under 0.017 ppm per year (environmental target of an annual average) in whole Yokkaichi observatory stations in Fig. 8b.

Fig. 6a SO₂ concentration in 1967 (max: 0.286 ppm).Fig. 6b SO₂ concentration in 1972.

現状(昭和46年)の汚染濃度分布 (ppb) SO₂

Fig. 7 Observed SO₂ concentration (max: 0.07 ppm) in 1971.

5. Compensation Costs Calculation in Yokkaichi in the Past

The number of patients did not decrease even if the concentration of sulfur oxides gas decreased in Yokkaichi in Fig. 8a. Therefore, the real number of patients of the respiratory illness does not decrease so suddenly to the future in Fig. 9a in Yokkaichi.

We predicted the number of each class of patients when environmental measures were not introduced in Yokkaichi in Fig. 9b. In other words, the pollution state of 1967 had continued all the time. As the result, the number of patients surpasses over 3,500, and the compensation expense would become the vast amount of money.

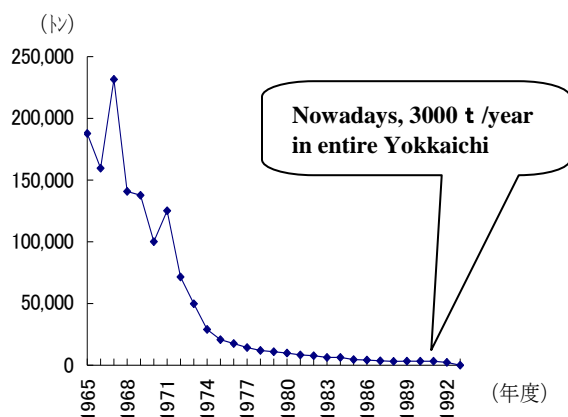


Fig. 8a SO₂ emission (ton) per year to the air in Yokkaichi.

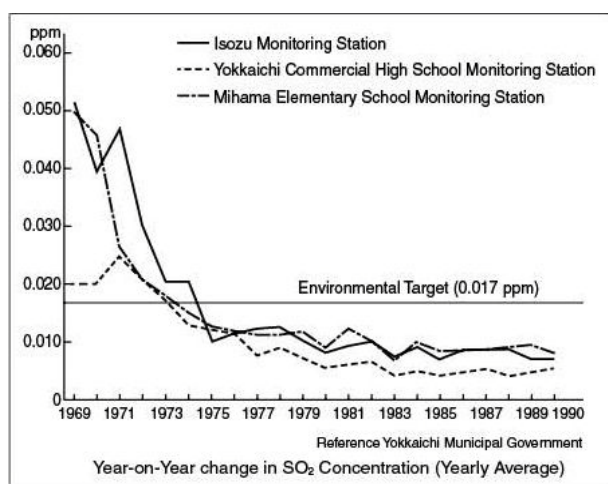


Fig. 8b Year-on-year change in SO₂ concentration in entire Yokkaichi.

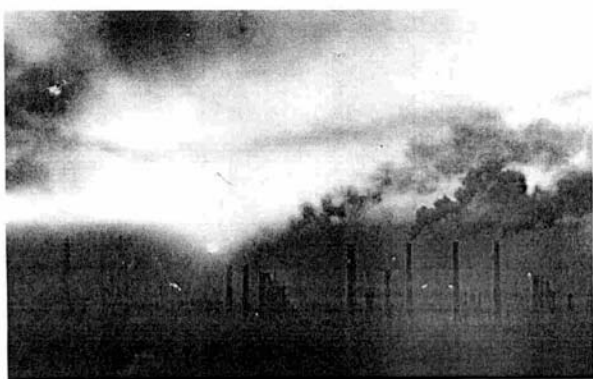


Fig. 8c View of the No. 1 petrochemical complex in Yokkaichi in 1960.

As few actual annual data exist prior to the 1970s, the compensation cost analyses in Yokkaichi are based on the following assumptions.

No. of certified patients (1966~)

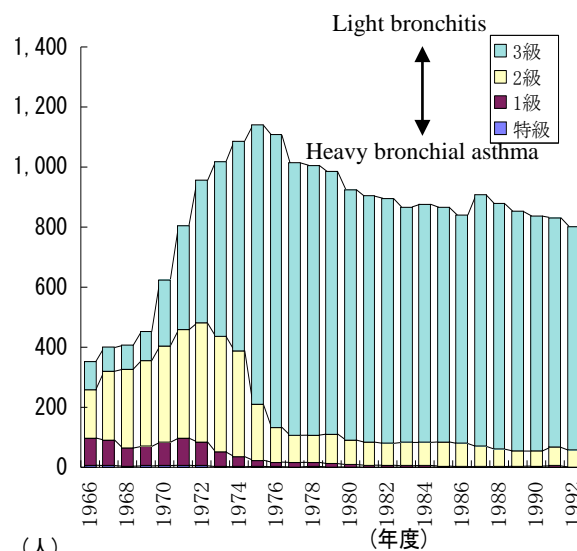


Fig. 9a Real number of certified sickness in each class of patients (1966-).

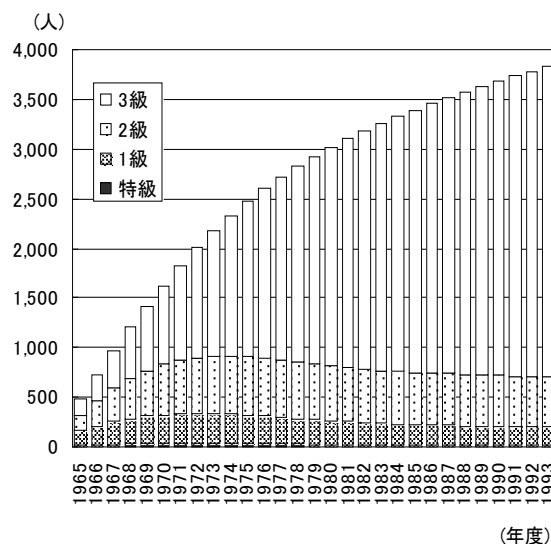


Fig. 9b Number of predicted sickness in each class of patients continuing without environmental measures from 1965.

Since environmental conditions were improving in Yokkaichi, the total cost of compensation for certified pollution victims would be overestimated if using cumulative account of compensation cases per year, but underestimated if only new cases were to be counted. Therefore, a hypothesis is adopted based on the worst data now available, those for the Isozu district in 1965. At that time, the annual average SO₂

concentration was 0.08 ppm in Isozu and the number of certified victims came to about 8% of the overall population. Thus, the hypothesis assumed here is that the 0.01 ppm increase in SO_2 concentration corresponds to a 1% increase in the number of certifiable pollution damage cases. Then, degree of pollution-related health damage depends on the annual average SO_2 concentration.

Table 2 gives the respective proportions of incidence for the 4 recognized classes at 4 different levels of SO_2 concentration (2 actually measured, 2 estimated). In order to estimate the number of victims in each class, these rates are applied to the estimated number of certified pollution victims in Yokkaichi in 1990. And SO_2 ppm values are observed data only in Isozu observation site.

Average annual compensation cost per person is shown in Table 3 for reference by converting it into a price of 1990. Given the actual annual decrease data of 7% in the number of certified victims, this gives an average compensation period of about 30 years per each case. But as it is hard to imagine that particularly severe health damage could continue for so long, a period of 10 years is assumed.

6. Relation Diagram between Antipollution Facilities Investment and Compensation Costs

The results obtained here are shown in Fig. 10. Corresponding to the different rates of annual average sulfur dioxide concentration (pollution rates, ppm unit) along the horizontal axis, the distinct characteristics can be discerned for each of the three historic periods [6].

At the lowest level of environmental investment, compensation costs rise to the astronomical amount of three hundred billion yen or more.

With the adoption of makeshift measures such as high chimneys, the short term economic expenses are kept to a minimum, but the results are not altogether from the environmental point of view.

Our finding is that where pollution preventing facilities are fully installed in Yokkaichi, the initial investment costs may be large, but the environment can be maintained in a healthy condition. Then, compensation costs are kept to a reasonable low level.

In Yokkaichi, pollution preventing facilities were fully installed, and the initial investment costs may be large over one hundred billion yen. And then, the atmospheric environment can be maintained under 0.01 ppm in SO_x to the healthy condition. These facts obtained in Yokkaichi indicated that the minimizing total investment plus compensation costs was not an adequate solution. So, companies had invested environmental facilities more aggressively.

We successfully demonstrate the relation between annual averaged SO_2 concentrations with ppm value and the total environmental investment costs plus compensation costs based on the experience of Yokkaichi [7].

Table 2 Certified patients ratio in Yokkaichi and yearly averaged SO_2 ppm values.

Class/ppm	0.02('74)	*0.05	0.06('67)	*0.08
Special class	0.33(%)	2.3	2.9	4.2
1st class	4.7	23.1	29.3	41.6
2nd class	42.7	35.7	33.3	28.6
3rd class	52.3	38.9	34.5	25.6
Certified patients ratio in Yokkaichi	0.02	0.05	0.06	0.08

Table 3 Compensation cost per person in each class (Yen).

Class	Compensation cost per year (yen)
Special	2,556,000
1st	2,052,300
2nd	1,026,150
3rd	615,690

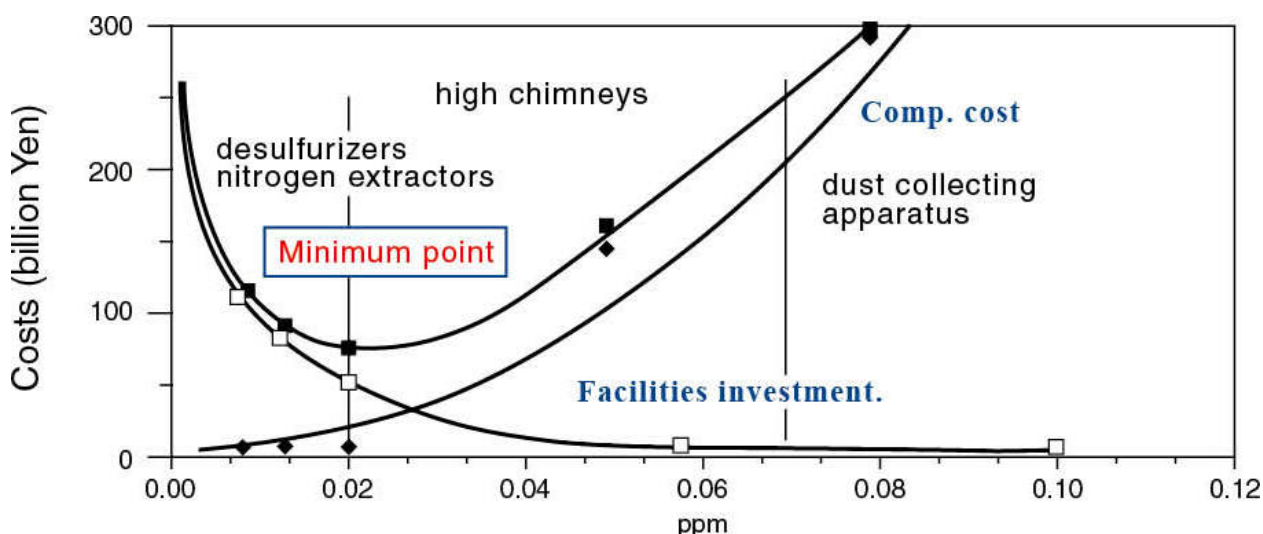


Fig. 10 Relation between SO_2 density (ppm) and the trade off of antipollution facilities investment plus compensation costs.

7. Conclusions

In this study, we have demonstrated the relation between annual average sulfur dioxide concentration (ppm) and total environmental investment costs (cost of pollution preventing equipment plus cost of compensation to certified victims) based on the experience of Yokkaichi. From the results obtained, it can be seen that minimizing total investment costs are not an adequate solution in Yokkaichi [8].

Unless positive investments are also undertaken for the prevention of pollution, it is impossible to maintain a healthy natural environment. In Yokkaichi, the flue gas desulfurizer was put into practical use in about 1970s with a great part of large-scale exhaust producing facilities, being completed from 1973 to 1977. And then sulfur dioxide levels have been kept within the environmental target of an annual average of 0.017 ppm since 1976 [9].

The recent rate of sulfur dioxide pollution in Yokkaichi stands at the quite low level of 0.006 ppm (1995). But the legacy of the 1960s pollution victims still remains in Fig. 9a. There were still approximately 500 certified pollution victims in Yokkaichi (2005).

We wish to express our thanks to the environment department of the Yokkaichi City administration and Mie Prefectural government for giving us access to several useful sources of data [10].

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