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Abstract

Plants absorb gaseous air pollutants from the atmosphere through stomata. In this study, the absorption of CO_2, SO_2 and NO_2 by the vegetation classified into 11 categories based on land use was evaluated from the net and gross production, and the area of each vegetation in Sakai city divided into 48 sections. As a result, the distribution of the gas absorption rate per unit area showed the gradient from the south mountainous area to the northwest commercial and industrial area. The total annual absorption of CO_2, SO_2 and NO_2 by the vegetation in Sakai was estimated to be 87 kt, 66 t and 77 t, respectively. The absorption of SO_2 and NO_2 was equivalent to 9.9 and 2.0 % of the exhaustion from the major stationary sources in Sakai, respectively. Moreover the NO_2 absorption was equivalent to 0.8 % of the total NO_2 exhaustion in Sakai. The vegetation in the tumuli in Sakai was the efficient sink of the gases, particularly NO_2.

Introduction

Plants absorb gaseous air pollutants from the atmosphere through stomata in the same way as CO_2 in photosynthesis. In order to control air pollution, it is important to take account of the gas absorption by plants as an atmospheric purification capacity. In this study, the absorption of CO_2 which is the primary greenhouse gas, SO_2 and NO_2 which are important air pollutants, by vegetation in Sakai city was evaluated from the net and gross production, and the area of the vegetation classified by land use.

Method

1. Study area

The study area was the whole of Sakai city which was divided into 48 sections (Fig.1). In Fig. 1, small sections of A and D were annexed to section 1, and sections B, C, E, F, G, H and I were annexed to sections 2, 3, 6, 16, 11, 17 and 46, respectively.

2. Measurement of vegetation area

Vegetation in the study area was classified into the following 11 categories based on land use: park trees, park shrubs, street trees, street shrubs, tumulus trees, grass, paddy, upland field, orchard, miscellaneous trees and shrubs. The tumuli defined here were the following 8 major ones with clear moats: Nintoku-ryo, Richu-ryo, Hanzei-ryo, Nisanzai-kofun, Goryoyama-kofun, Itasuke-kofun, Nagayama-kofun and Maruhoyama-kofun; these are located in the sections 9, 13, 14, 19 and 20. The miscellaneous trees and shrubs included forests in mountainous areas, terraces,

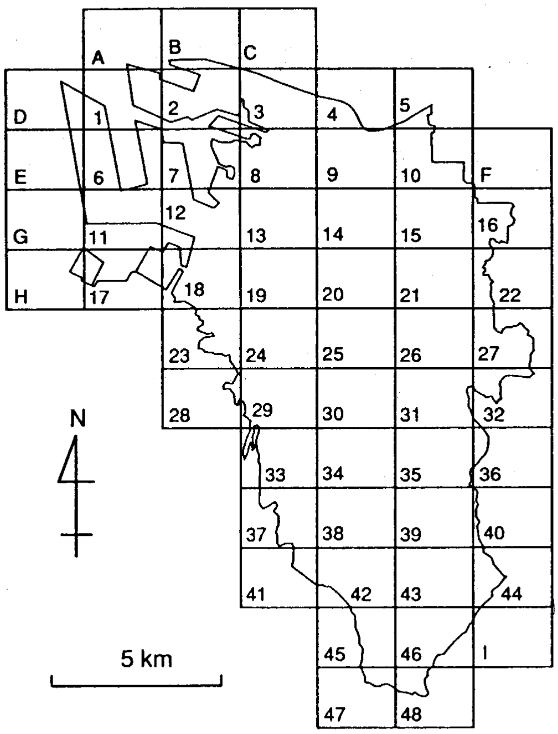

Fig. 1 Sakai city divided into sections

temples, shrines, *etc*.

A vegetation map was drawn on a scale of 1/20000 from aerial photographs taken in 1990. The map was taken into a personal computer with an image scanner (GT-4000, EPSON), and the area of each vegetation was determined with the computer in each section.

3. Formulation of gas absorption[1,2]

The absorption rates of CO_2 and gaseous air pollutants by vegetation can be written as follows:

$$U_{CO_2} = K_{CO_2} \cdot C_{CO_2} \cdot A \quad (1)$$

$$U_{gas} = K_{gas} \cdot C_{gas} \cdot A \quad (2)$$

$$U_{gas}/U_{CO_2} = (K_{gas}/K_{CO_2}) \cdot (C_{gas}/C_{CO_2}) \quad (3)$$

where U is the gas absorption rate, K is the leaf diffusive conductance, C is the gas concentration in the atmosphere and A is the vegetation area. U_{CO_2} refers to the gross photosynthetic rate. With the weight ratio of polysaccharide (regarded as $C_6H_{10}O_5$) forming almost all parts of plants to absorbed CO_2 in the photosynthesis, which is 1.63 ($= 6\,CO_2/C_6H_{10}O_5$), the eq. (1) is modified as follows:

$$U_{CO_2} = 1.63P_g \cdot A \quad (4)$$

where P_g is the gross production (t (dry matter) ha^{-1} $year^{-1}$) and units of U and A are t $year^{-1}$ and ha, respectively. However, in order to calculate the net CO_2 absorption rate, it is necessary to substitute the net production (P_n) for P_g in the eq. (4); the P_n is the remainder after subtracting the depletion through respiration from P_g. When SO_2 and NO_2 are considered gaseous air pollutants, the following equations can be derived by substituting eq. (4), $C_{CO_2} = 0.63\,\mu g\ cm^{-3}$ (350 ppmv, 25℃), $K_{SO_2}/K_{CO_2} = 8$ and $K_{NO_2}/K_{CO_2} = 6$ for eq. (3) :

$$U_{SO_2} = 20.7\, C_{SO_2} \cdot P_g \cdot A \quad (5)$$
$$U_{NO_2} = 15.5\, C_{NO_2} \cdot P_g \cdot A \quad (6)$$

With conversion coefficients of $2.62 \cdot 10^{-6}$ and $1.88 \cdot 10^{-6} \mu g\ cm^{-3}\ ppbv^{-1}$ for SO_2 and NO_2 at 25℃, respectively, the eqs. (5) and (6) become as follows :

$$U_{SO_2} = 0.0542\, C_{SO_2} \cdot P_i \cdot A \quad (7)$$
$$U_{NO_2} = 0.0291\, C_{NO_2} \cdot P_g \cdot A \quad (8)$$

where units of U and C are kg $year^{-1}$ and ppbv, respectively.

4. Determination of P_n and P_g of each vegetation

The P_n and P_g of the vegetation classified in this study were determined on the basis of those of conifer trees, deciduous broad-leaved trees, evergreen broad-leaved trees, grass, paddy, upland field, *etc.*, determined by Miyake[2] and Iwaki[3]. The P_n and P_g of the park, street, tumulus and miscellaneous trees were calculated from the occupancy ratios of conifer, deciduous broad-leaved and evergreen broad-leaved trees, which were estimated on the basis of some reports[4,5,6].

5. Concentration of SO_2 and NO_2

The NO_2 concentration used in this study was the annually averaged mesh-data[7] which was computed in 1988 with an atmospheric diffusion model (Fig. 2). On the other hand, as SO_2 concentration, the mean (9.9 ppbv) of the annual averages of the 10 air pollution monitoring stations in Sakai city was used all over the sections because of no mesh-data.

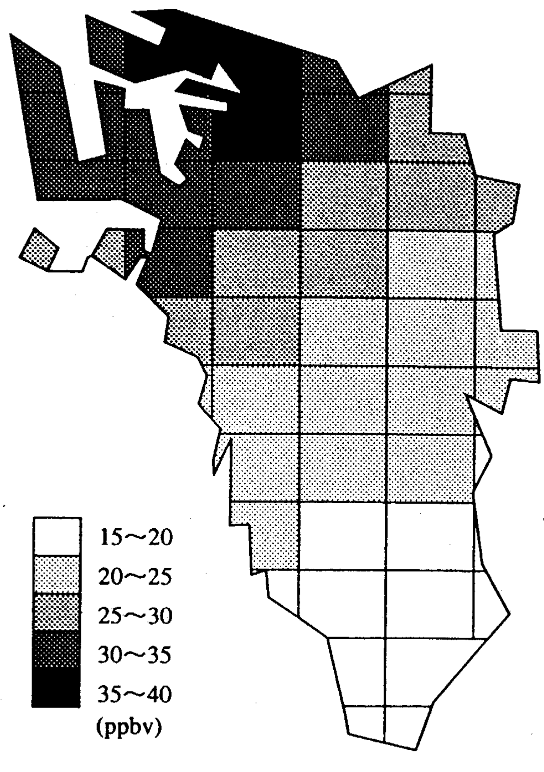

Fig. 2 Distribution of annual average of NO_2 concentration in Sakai city (1988)[7]

Results and Discussion

1. Vegetation in Sakai city

Table 1 shows the area of each vegetation and the vegetation cover in each section. The vegetation occupying the largest area was the grass, and followed by the paddy, miscellaneous trees, upland field, park trees, orchard, park shrubs, miscellaneous shrubs, tumulus trees, street trees and street shrubs in the order of area. The vegetation cover was 35.5% in total, and the distribution indicated that the vegetation cover was larger in the south mountainous area and smaller in the northwest commercial and industrial area (Fig. 3).

Table 1 Areas of vegetation in each section (1990)

No.	Land	Park		Street		Tumulus	Grass	Paddy	Upland field	Orchard	Miscellaneous		Total	Vegetation cover(%)
		Tree	Shrub	Tree	Shrub						Tree	Shrub		
1	270.5	0.0	0.0	0.0	0.0	0.0	9.2	0.0	0.0	0.0	0.0	0.0	9.2	3.4
2	364.3	13.3	2.1	0.0	0.0	0.0	11.6	0.0	0.0	0.0	0.0	0.0	27.0	7.4
3	343.2	5.9	0.5	0.0	0.3	0.0	12.0	0.0	13.0	0.0	0.3	0.0	31.9	9.3
4	122.7	3.3	1.2	0.0	0.0	0.0	2.8	0.0	1.3	0.0	0.8	0.1	9.6	7.8
5	60.9	0.0	0.0	0.0	0.0	0.0	0.6	0.7	2.8	0.0	0.0	0.0	4.1	6.8
6	335.0	0.0	1.1	0.0	0.4	0.0	87.5	0.0	0.0	0.0	0.0	0.0	89.0	26.6
7	234.2	2.8	0.3	1.7	0.9	0.0	6.1	0.0	0.0	0.0	0.0	0.0	11.7	5.0
8	412.5	10.5	0.6	0.7	0.0	0.0	7.9	0.0	0.5	0.0	0.0	0.0	20.3	4.9
9	424.8	8.1	3.0	0.3	0.0	1.5	17.6	7.4	7.4	0.0	2.4	0.3	47.9	11.3
10	286.5	5.4	7.0	0.0	1.6	0.0	11.8	24.6	11.4	0.0	0.3	0.1	62.0	21.6
11	251.2	1.1	8.2	0.0	0.7	0.0	14.3	0.0	0.0	0.0	0.0	0.0	24.3	9.7
12	360.7	13.5	1.6	5.2	1.1	0.0	26.7	0.0	9.9	0.0	0.0	0.0	58.0	16.1
13	421.1	17.1	1.9	0.9	0.3	9.4	7.2	0.0	2.0	0.0	1.2	0.0	40.0	9.5
14	421.1	7.3	2.6	0.0	0.0	29.9	16.6	19.3	18.9	0.8	4.2	5.1	104.6	24.8
15	421.1	43.0	1.0	0.0	0.0	0.0	21.2	85.5	16.6	0.5	0.9	1.0	169.6	40.3
16	158.8	0.0	0.2	0.0	0.0	0.0	4.5	61.1	24.3	0.0	0.0	0.0	90.0	56.7
17	124.7	0.0	5.2	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	6.8	5.4
18	365.2	27.3	3.2	2.7	0.8	0.0	12.2	0.9	12.6	2.1	0.4	0.3	62.4	17.1
19	421.1	10.9	2.1	0.0	0.8	2.1	20.1	3.3	23.2	1.1	4.0	0.6	68.1	16.2
20	421.1	13.2	3.1	0.0	0.0	5.4	20.5	24.7	40.0	2.7	3.4	0.4	113.3	26.9
21	421.1	4.6	1.5	0.0	0.0	0.0	17.9	45.9	17.8	0.1	1.7	1.0	90.5	21.5
22	107.8	0.0	0.0	0.0	0.0	0.0	1.9	29.6	8.1	0.3	0.0	0.0	39.9	37.0
23	164.7	1.2	0.6	0.0	0.0	0.0	3.8	3.3	22.2	0.8	1.7	0.0	33.6	20.4
24	421.1	4.7	3.0	0.0	0.2	0.0	22.4	12.0	42.5	1.4	9.3	4.7	100.1	23.8
25	421.1	2.0	4.8	0.0	0.1	0.0	23.5	35.4	57.8	3.2	3.9	3.5	134.2	31.9
26	421.1	1.5	0.8	0.0	0.0	0.0	29.4	35.2	94.4	1.5	2.6	8.2	173.6	41.2
27	261.6	1.1	5.4	0.0	0.0	0.0	11.9	62.8	26.9	2.1	2.2	0.5	112.8	43.1
28	17.9	0.0	0.0	0.0	0.0	0.0	0.7	7.7	1.1	0.2	0.0	0.3	10.0	55.7
29	399.0	2.2	3.5	0.0	0.0	0.0	55.7	82.4	34.4	1.7	6.9	10.2	196.9	49.3
30	421.1	7.7	2.4	0.6	0.2	0.0	64.5	49.8	48.3	5.7	17.6	2.3	199.0	47.3
31	415.9	0.3	7.1	0.0	0.0	0.0	33.5	92.2	95.5	3.2	12.2	11.5	255.4	61.4
32	104.3	0.1	0.0	0.0	0.0	0.0	7.4	13.4	18.6	2.5	5.2	0.1	47.3	45.3
33	333.9	8.3	5.2	0.0	0.0	0.0	48.3	49.5	20.3	2.4	16.0	12.4	162.4	48.6
34	421.1	42.3	5.0	0.2	1.7	0.0	47.1	56.1	22.9	0.8	12.8	1.5	190.3	45.2
35	419.9	44.5	14.9	8.1	4.0	0.0	33.5	0.3	2.6	0.5	13.3	3.7	125.3	29.8
36	44.9	5.6	0.4	0.0	0.0	0.0	2.5	0.0	3.1	0.2	1.3	0.7	13.8	30.8
37	227.5	22.2	6.6	1.3	1.2	0.0	24.5	5.3	6.6	0.5	6.3	1.1	75.6	33.2
38	421.1	17.0	2.6	0.7	1.2	0.0	65.9	67.6	13.7	1.4	31.4	4.2	205.7	48.8
39	421.1	9.4	5.1	0.3	0.0	0.0	63.0	119.3	15.7	0.8	86.4	4.8	304.8	72.4
40	30.4	0.7	0.3	0.0	0.0	0.0	3.5	1.3	1.1	0.3	21.7	0.0	28.9	94.9
41	54.2	16.7	1.3	0.0	0.0	0.0	20.0	0.0	0.0	0.0	0.5	0.0	38.6	71.1
42	362.3	26.5	4.1	1.7	0.0	0.0	51.0	31.9	10.0	15.9	67.6	16.8	225.5	62.3
43	421.1	9.9	1.0	0.0	0.0	0.0	63.1	54.4	5.3	4.2	227.8	0.3	366.1	86.9
44	117.6	0.0	0.0	0.0	0.0	0.0	64.7	3.2	0.5	0.8	38.6	0.0	107.7	91.5
45	197.5	0.0	0.0	0.0	0.0	0.0	13.9	12.7	4.9	71.8	67.8	1.6	172.7	87.4
46	319.9	0.0	0.0	0.0	0.0	0.0	100.7	0.1	0.2	15.8	192.6	0.0	309.3	96.7
47	33.4	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.1	16.5	13.8	0.0	31.5	94.1
48	53.8	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	5.7	46.7	0.0	53.8	100.0
Total	13677	411	120	24	15	48	1189	1099	758	167	925	97	4855	35.5

Unit : ha

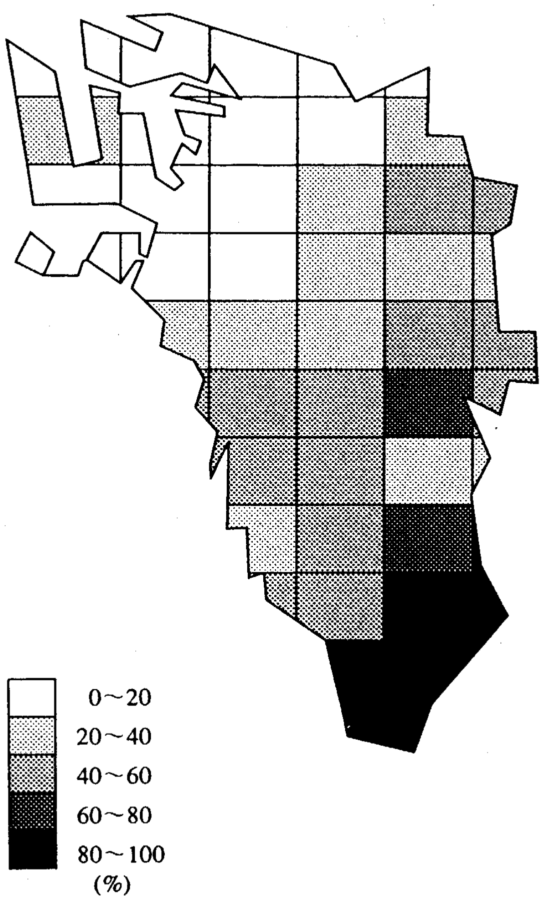

Fig. 3 Distribution of vegetation cover in Sakai City (1990)

Table 2 shows the P_n and P_g determined in each vegetation. Since the tumulus trees were dominated by evergreen broad-leaved trees with high productivity, their P_n and P_g were higher.

2. Absorption of CO_2, SO_2 and NO_2 by vegetation

The Absorption rates of CO_2, SO_2 and NO_2 by the vegetation, and the distribution are shown in Table 3 and Fig. 4, respectively.

The amount of CO_2 absorbed annually by the vegetation from the atmosphere in Sakai was 86.61 kt in total and 6.33 t ha^{-1} per unit area. In comparison with the amount in the whole of Osaka prefecture in 1980 (1529 kt $year^{-1}$ and 8.2 t ha^{-1} $year^{-1}$) evaluated by Miyake[2] in the same way as this study, the amount in Sakai was equal to 5.7 % of that in Osaka prefecture (86.61: 1529), and the amount per unit area was equl to 77 %

Table 2 Net and gross production of vegetation

Vegetation		Net production (t ha^{-1} $year^{-1}$)	Gross production (t ha^{-1} $year^{-1}$)
Park	Tree	15	49
	Shrub	8	24
Street	Tree	12	34
	Shrub	8	26
Tumulus	Tree	17*	51*
Grass		8	16
Paddy		11	18
Upland field		12	20
Orchard		10	20
Miscellaneous	Tree	13	40
	Shrub	9	24

*Mean of 8 tumuli in Sakai

Table 3 Annual absorption rates of CO_2, SO_2 and NO_2 by vegetation in Sakai city

No.	CO_2		SO_2		NO_2		No.	CO_2		SO_2		NO_2	
	kt y^{-2}	t $ha^{-1}y^{-1}$	t y^{-1}	kg$ha^{-1}y^{-1}$	t y^{-1}	kg$ha^{-1}y^{-1}$		kt y^{-2}	t $ha^{-1}y^{-1}$	t y^{-1}	kg$ha^{-1}y^{-1}$	t y^{-1}	kg$ha^{-1}y^{-1}$
1	0.12	0.44	0.08	0.29	0.13	0.49	25	2.28	5.41	1.44	3.43	1.87	4.45
2	0.50	1.38	0.48	1.31	0.93	2.54	26	2.95	7.02	1.83	4.35	2.16	5.14
3	0.55	1.60	0.41	1.20	0.83	2.42	27	1.95	7.45	1.17	4.47	1.37	5.24
4	0.18	1.43	0.16	1.30	0.28	2.32	28	0.17	9.72	0.10	5.47	0.13	7.08
5	0.07	1.16	0.04	0.69	0.07	1.11	29	3.25	8.13	2.04	5.12	2.58	6.46
6	1.16	3.46	0.77	2.30	1.29	3.86	30	3.34	7.94	2.27	5.38	2.74	6.51
7	0.20	0.83	0.17	0.73	0.33	1.39	31	4.38	10.53	2.75	6.60	3.04	7.32
8	0.39	0.95	0.37	0.90	0.73	1.78	32	0.82	7.90	0.53	5.12	0.61	5.82
9	0.84	1.98	0.66	1.55	1.13	2.67	33	2.72	8.16	1.92	5.76	2.15	6.44
10	1.05	3.66	0.72	2.52	1.12	3.91	34	3.53	8.38	2.70	6.40	3.12	7.40
11	0.33	1.31	0.27	1.07	0.45	1.77	35	2.40	5.71	2.22	5.29	2.48	5.90
12	0.99	2.75	0.82	2.28	1.49	4.13	36	0.28	6.26	0.25	5.49	0.26	5.88
13	0.90	2.13	0.89	2.12	1.57	3.74	37	1.40	6.14	1.20	5.26	1.30	5.72
14	2.15	5.10	1.82	4.31	2.83	6.73	38	3.57	8.49	2.62	6.22	2.74	6.51
15	3.21	7.63	2.37	5.62	3.63	8.61	39	5.47	13.00	4.10	9.75	3.89	9.23
16	1.59	10.02	0.89	5.61	1.27	8.02	40	0.58	18.90	0.55	17.92	0.52	16.96
17	0.09	0.71	0.08	0.65	0.13	1.04	41	0.73	13.37	0.64	11.79	0.66	12.20
18	1.22	3.34	1.10	3.02	1.87	5.13	42	4.13	11.41	3.47	9.59	3.33	9.20
19	1.21	2.88	0.95	2.25	1.48	3.51	43	7.07	16.78	6.34	15.05	5.59	13.27
20	2.07	4.91	1.50	3.56	2.11	5.02	44	1.74	14.78	1.43	12.13	1.24	10.54
21	1.56	3.71	0.98	2.32	1.27	3.02	45	3.13	15.83	2.54	12.86	2.20	11.13
22	0.71	6.55	0.39	3.64	0.50	4.61	46	5.65	17.68	5.17	16.16	4.20	13.13
23	0.59	3.60	0.39	2.35	0.58	3.52	47	0.58	17.27	0.48	14.46	0.40	11.97
24	1.71	4.07	1.20	2.86	1.66	3.95	48	1.10	20.46	1.08	19.99	0.87	16.21
							Total	86.61	6.33	66.34	4.85	77.14	5.64

(6.33 : 8.2). The 5.7 % was smaller than the areal ratio (7.3 %) of Sakai to Osaka prefecture. This was caused by less mountainous forest in Sakai, which is the major sink of CO_2. The distribution of the CO_2 absorption rate per unit area corresponded to that of the vegetation cover (Fig. 3); the absorption rate was higher in the south and lower in the northwest. The section having the highest absorption rate (20.46 t ha^{-1} $year^{-1}$) was No. 48 at the south end (Fig. 1), where the vegetation cover was 100%, and the section 1 in reclaimed land, with the vegetation cover of 3.4 %, had the lowest rate (0.44 t ha^{-1} $year^{-1}$). The former was 47 times as high as the latter.

The annual amount of SO_2 absorbed by the vegetation in Sakai was 66.34 t in total and 4.85 kg ha^{-1} per unit area. The amount in Sakai was equal to 3.7 % of that in Osaka prefecture in 1980 (1800 t $year^{-1}$ and 9.7 kg ha^{-1} $year^{-1}$)[2], and the amount per unit area was equl to 50 %. This smaller ratio (3.7 %) compared with the areal one was caused by not only the less mountainous forest in Sakai but also the higher SO_2 concentration (13.1 ppbv) used by Miyake[2]. The absorbed SO_2 of 66.34 t $year^{-1}$ was equivalent to 9.9 % of the exhausted SO_2 (672 t $year^{-1}$)[8] from the major stationary sources in Sakai in 1990. Since SO_2 concentration was assumed to be equal all over Sakai city, the distribution of the absorption rate corresponded to that of the vegetation cover (Fig. 3) similarly to the case of CO_2. For the same reason, the SO_2 absorption was probably overestimated because SO_2 concentration was most likely lower in the south where the vegetation cover was higher, similarly to NO_2 concentration (Fig. 2). The sections with the highest and lowest absorption rates were No. 48 (19.99 kg ha^{-1} $year^{-1}$) and No. 1 (0.29 kg ha^{-1} $year^{-1}$), respectively. The former was 69 times as high as the latter.

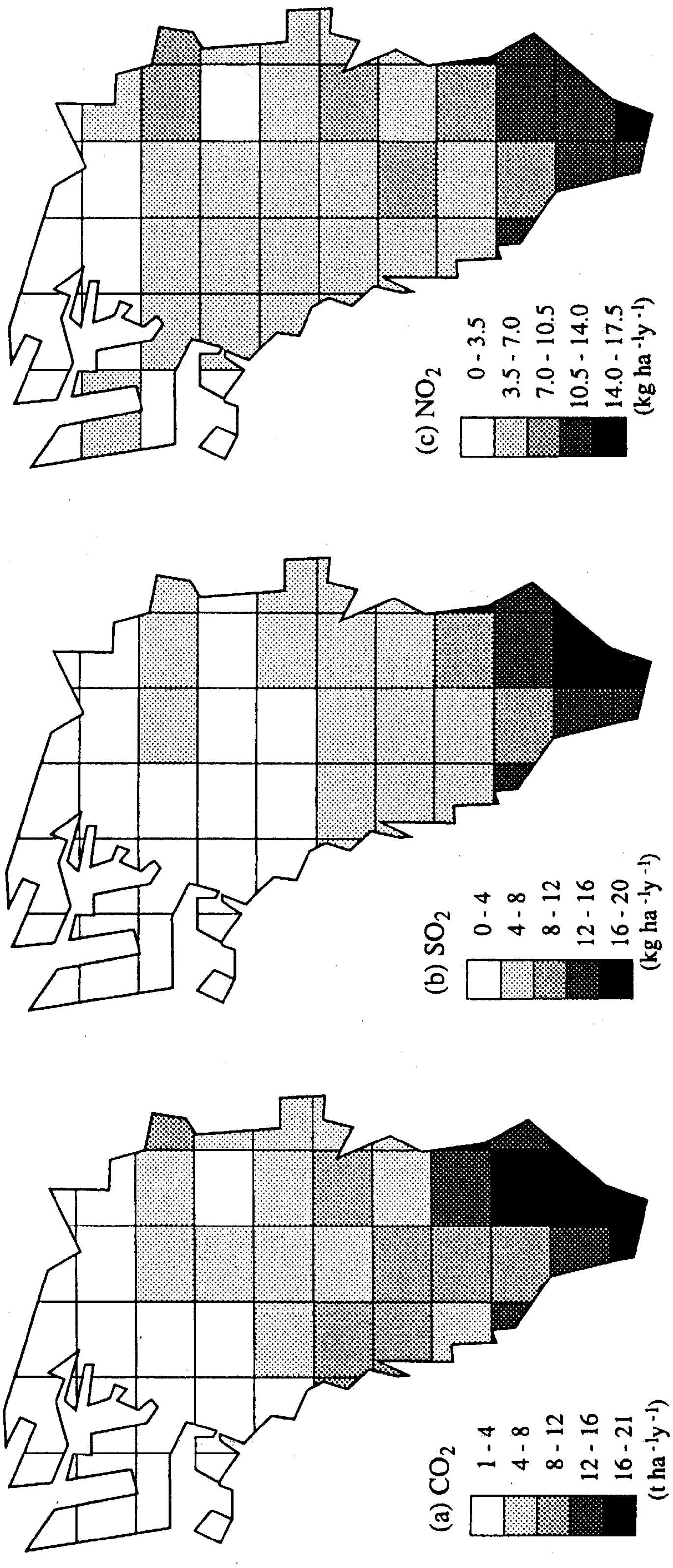

Fig. 4　Distribution of absorption rates of CO_2, SO_2 and NO_2 by vegetation in Sakai

The amount of NO_2 absorbed by the vegetation in Sakai was 77.14 t $year^{-1}$ in total and 5.64 kg $year^{-1}$ ha^{-1} per unit area. The amount in Sakai was equal to 4.2 % of that in Osaka prefecture in 1980 (1847 t $year^{-1}$ and 9.9 kg ha^{-1} $year^{-1}$)[2], and the amount per unit area was 57 %. On the other hand, in comparison with the amount in Osaka prefecture (20.19 kt $year^{-1}$ and 107.32t ha^{-1} $year^{-1}$) evaluated by Kobayashi *et al.*[9] using deposition velocity, the amount in Sakai was only 0.4 % of that in Osaka prefecture, and the amount per unit area was 5.3 %. While the distribution of the absorption rate showed the gradient from the south to the north, the sectional difference was smaller than the cases of CO_2 and SO_2 because NO_2 concentration was higher in the northwest (Fig. 2). The sections with the highest and lowest absorption rates were No. 40 (16.96 kg ha^{-1} $year^{-1}$) and No. 1 (0.49 kg ha^{-1} $year^{-1}$), respectively. The former was 35 times as high as the latter.

In Sakai, the NO_2 exhaustion from the major stationary sources was 3921 t $year^{-1}$ in 1990[8], and the total exhaustion from both the stationary and mobile sources was estimated to be 9291 t $year^{-1}$ from the ratio of the exhaustion from each source in Osaka area[10]. Thus the absorbed NO_2 (77.14 t $year^{-1}$) by vegetation was equivalent to 2.0 % of the former and 0.8 % of the latter.

Between the absorbed NO_2 evaluated from the gross production[2] and deposition velocity[9], there was great difference. The evaluation by Kobayashi *et al.*[9] seems to be overestimated for the following reasons : 1) the annual evaluation was made with one deposition velocity in a summer season and 2) deciduous and evergreen trees were dealt with the same. In contrast with this, the evaluation by using the gross production seems to have no problem related to the seasonal change of vegetation because it is based on the annual growth of each vegetation. In this study, however, the P_n and P_g determined from those of native species in mountainous areas were used for the urban vegetation which includes many alien species and grows under the environmental stress such as air pollution; this remains as a problem.

3. Absorption of CO_2, SO_2 and NO_2 by tumulus vegetation

Table 4 shows the absorption rates of CO_2, SO_2 and NO_2 by tumulus vegetation. Although the total vegetation area in the tumuli occupied only 1% of that in Sakai city (4855 ha, Table 1), the absorption rates of CO_2, SO_2 and NO_2 by the tumulus vegetation were equivalent to 1.62, 2.21 and 3.09 % of those in the whole city, respectively. Nintoku-ryo called as the largest tumulus

Table 4 Annual absorption rates of CO_2, SO_2 and NO_2 by the vegetation in the major tumuli in Sakai

Tumulus	Vegetation area	Net production	Gross production	Absoption rate		
	(ha)	(t $ha^{-1}y^{-1}$)	(t $ha^{-1}y^{-1}$)	CO_2 (t y^{-1})	SO_2 (kg y^{-1})	NO_2 (kg y^{-1})
Nintoku-ryo	29.60 (0.61)*	19	57	869 (1.00)*	905(1.36)*	1507 (1.95)*
Richu-ryo	7.52 (0.15)	19	57	221 (0.26)	230 (0.35)	383 (0.50)
Hanzei-ryo	1.49 (0.03)	20	67	49 (0.06)	54 (0.08)	91 (0.12)
Nisanzai-kofun	4.69 (0.10)	19	57	138 (0.16)	143 (0.22)	202 (0.26)
Gobyoyama-kofun	1.97 (0.04)	19	57	58 (0.07)	60 (0.09)	94 (0.12)
Itasuke-kofun	1.63 (0.03)	17	51	43 (0.05)	45 (0.07)	70 (0.09)
Nagayama-kofun	0.76 (0.02)	15	41	16 (0.02)	17 (0.03)	26 (0.03)
Maruhoyama-kofun	0.60 (0.01)	10	22	9 (0.01)	10 (0.01)	11 (0.01)
Total	48.26 (0.99)	—	—	1403 (1.62)	1464 (2.21)	2384 (3.09)

* Percentage of the total rate by the whole vegetation in Sakai (Table 3) .

in Japan had the vegetation area of 29.60 ha which was equal to 0.61 % of that in the whole city, and the absorption rates of CO_2, SO_2 and NO_2 were equivalent to 1.00, 1.36 and 1.95 % of those in the whole city, respectively. Therefore the vegetation in the tumuli is the efficient sink of CO_2, SO_2 and especially NO_2, because evergreen broad-leaved trees with large P_n and P_g dominate in the tumulus vegetation and the tumuli are located in the urban area where NO_2 concentration is relatively high.

Conclusion

As the result of this study, the annual absorption of CO_2, SO_2 and NO_2 by the vegetation in the whole of Sakai city was estimated to be 87 kt, 66 t and 77 t, respectively, from the net and gross production. The absorption of SO_2 and NO_2 was equivalent to 9.9 and 2.0 % of the exhaustion from the major stationary sources in Sakai, respectively. Moreover the NO_2 absorption was equivalent to 0.8 % of the total NO_2 exhaustion in Sakai. The gas absorption rate in Sakai was lower than that in Osaka prefecture; this is probably caused by the less mountainous forest in Sakai. The distribution of the gas absorption rate showed the gradient from the south mountainous area to the northwest commercial and industrial area. In addition, it became clear that the vegetation in the tumuli in Sakai is the efficient sink of CO_2, SO_2 and especially NO_2.

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