GIS Based Modeling and Simulation System for Assessing CO2 Emission Caused by Regional Suburbanized Activities Growth

GIS によるモデリングとシミュレーション・システムを用いた地域の郊外化の発展に伴 う CO2 排出量算定

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Abstract; This research attempts to estimate the environmental impacts caused by regional suburbanized activities growth such as emissions, natural loss, and wastes. GIS based modeling and simulation system is constructed for assessing CO_2 emission caused by the growth of suburbanized activities in the regional scale. Case study in Muko River Basin Region, Hyogo Prefecture, Japan is carried out based on the GIS data of 1km grids as well as statistics data for land use, population allocation, urban activities and other social economical activities in the Region. Comparative analysis, modeling and simulation system for the environmental changes assessment of related impacts between 1975s and 1995 in the Region are done as follows; First "regression models" to explain the correlation of the environmental changes with several explanatory variables including population, urban activities and other variables are designed. Secondly the environmental loads such as CO_2 are estimated by regressed parameters and other indicators. Finally, significant environmental impacts caused by the growth of urban activities and suburbanization effects are identified.

Keywords; *GIS, Suburbanized activities, CO_2 Emission, Environmental Impact Assessment, Regression models*

1. INTRODUCTION:

One of the main challenges to Japanese environment management process and planning system in postwar Japan has been the rapid increase of urban areas and activities. The growth of population and socio-economic activities in expanding metropolitan regions in Japan, has led to serious environmental loads to the nature and its resources preservation ability. The continues improvement of infrastructure such as railways construction and automobile express-way network have resulted in the expansions of suburbanized areas and the areas of large scale urban facilities, which consequently caused a lot of global environmental emissions such as CO_2 as well as local contaminations[1].

This paper presents a GIS based modeling and simulation system to assess the Environmental Impacts caused by the growth of suburbanization activates in Hyogo Prefecture, a west part of Kansai Metropolitan Region, Japan, focusing on Muko River Basin Region as an objective for the study, fig. 1. The study attempts to estimate the environmental impacts caused by the growth of urban activities and suburbanization effects based on GIS data base analysis. The analysis focuses on studying the relation between the growth of urban activities and related increase of environmental loads in the Region. The models of the analysis estimate the environmental impacts such as natural loss and CO_2 emission in the regional scale of Muko River Region.

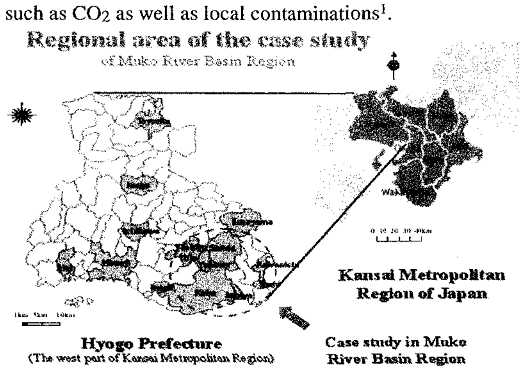

Fig. 1 Regional Location of the case study of Muko River Region

2. MUKO RIVER BASIN REGION DATA SET PROCESSING

2.1 GIS Data-Base System for Regional Environmental Impacts Assessment

An integrated GIS based study is constructed for the modeling and simulation system as 1km grid statistics data to analyze the environmental changes and related impacts caused by suburbanization effects of the intensive development process of residential and commercial facilities with related emissions in these areas of Muko River Basin Region[7], based on a comparative analysis between 1975s and 1995s for the considered data as shown in fig. 2. Environmental impact such as CO_2 Emissions brought by increasing of commercial activities and automobile access to shopping areas, and residential facilities are identified by 1km grid GIS data with their spatial patterns.

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The data considered in the analysis included various types (1km grid, Statistics, Coverage, Spatial, Paper maps data and others) as follows:

(1) 1km grid GIS data for population, land use and land cover categories, etc (1975 to 1995).
(2) Statistical 1km grid data (1975 to 1995).
(3) Japan Statistical Yearbook Data, 2003.
(4) Road Traffic Census and transportation Data in Hanshin area, Hyogo Prefecture (1977, 1997).
(5) Other coverage data for the analysis.

The outputs of data analysis give key factors for policy recommendations for future sustainable development and regional activities management, as shown in the framework in fig 3.

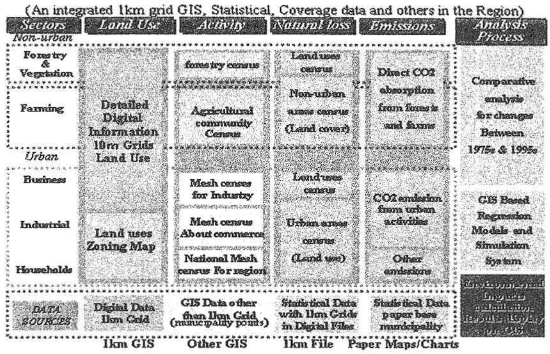

Fig. 2 An Integrated Data-base System for the Analysis

2.2 Framework for GIS-Based Modeling and Simulation System

The system was obtained by comprehensive various categories and types of regional data inputs for the analysis such as land uses, transportation network, automobile trips for shopping, and population allocation. Social activity data such as commercial sales and large scale stores allocation are also converted into 1km grid data as well as transportation accessibility of automobile ways in this Region[5]. The data have been made for time-series comparative analysis between 1975s and 1995s for estimating CO_2 emission changes caused by automobile trips to shopping areas in the region and related factors as outputs for the system, fig. 3.

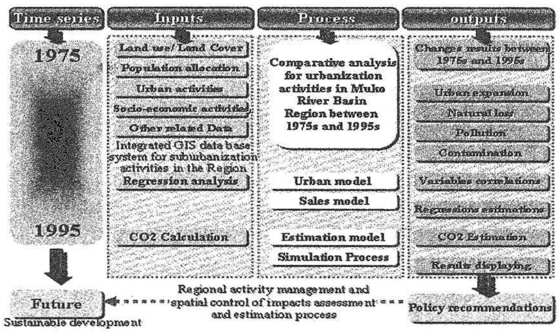

Fig. 3 The Modeling Process inputs and outputs framework

3. DRIVING FORCES ANALYSIS Of ENVIRONMENTAL IMPACTS IN MUKO REGION

Urbanization and socio-economic activities growth in Muko River Basin Region constitute the major driving forces of environmental impacts such as natural loss, air pollution, water contamination and CO_2 Emissions, which result in considerable changes in the environment. Environmental impact elements brought by several regional driving forces and regional management policies are identified by 1km grid data with their spatial patterns.

Monitoring of such changing of the environment, the population and urban activities changes are among the most critical information for future sustainable development, and environmental and ecosystem management. The analysis is carried out based on considered data of population and suburbanized activities in Nishinomiya, Takarazuka, Kita-Kobe, Sanda, Amagasaki, Itami and Ashia cities of Muko River Region. Spatial patterns of environmental indicators are defined such as the loss of natural land covers, and carbon dioxide emissions. The relationship between driving forces of the environmental impacts is analyzed by decomposing aggregated environmental impacts into several elements attributable to the driving forces[4], the driving forces cause-effect analysis as shown in fig 4.

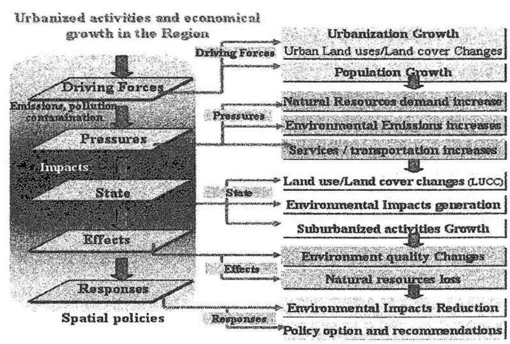

Fig. 4 Cause-effect analysis for urban activities and related environmental effects in Muko River Basin Region

3.1 Population Growth in Muko River Basin Region

The population in Muko River Basin Region increased from 1.5 in 1975 to 1.7 million in 1995[3], Fig.5 shows the locational distribution of district of the increase and decrease of the population in two decades. While population found grown in suburban districts, these are districts which lost the population in the downstream area, which can be considered due to the inner city situation. The population growth in these areas brought several changes to land use and land cover in the region which resulted in the loss of forests and green areas in the Region as shown in Figs 6 and 7, which show the areas of natural loss are the same of the areas of suburbanized areas and activities growth.

3.2 Urban Growth in Muko River Region

Figure 6 shows the distribution of the loss of the forest areas and greens in the region in two decades. The areas of natural loss are those which got the increase of population in the middle stream areas of the Region. The opposite has been happened in Fig. 7 which shows the distribution of the expansion of urban areas in the Region in the same period. These areas of urban expansion are those which found loss of natural areas, got growth of urban activities and growth of population in suburban districts. These are districts which found grown the population in the middle stream areas led to the increase of urban activities which resulted in increasing of urban land uses as well as the expansion of suburbanized areas and activities[5], Fig 8 and 9.

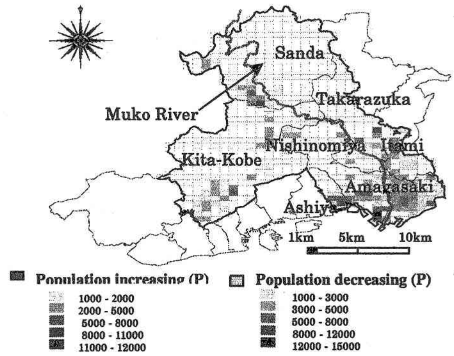

Fig.5 Population changes in Muko Region 1975s – 1995s

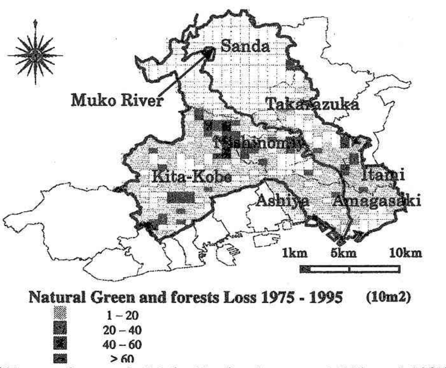

Fig.6 Forest changes in Muko Region between 1975s and 1995

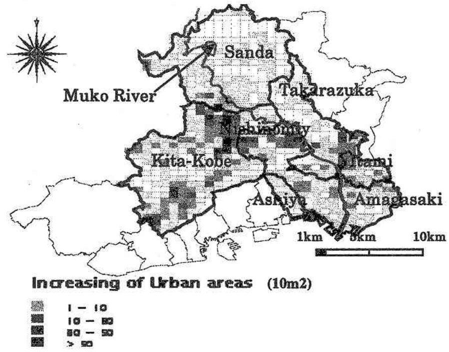

Fig.7 Urban changes in Muko Region between 1975s and 1995

These changes and expansion of suburbanized urban activities and areas consequently caused a lot of regional environmental loads such as natural loss, CO_2 emissions and local contaminations.

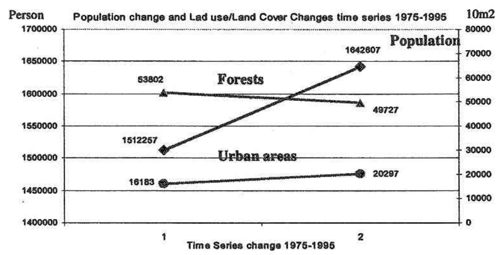

Fig. 8 Population and Urban / non-urban changes relation

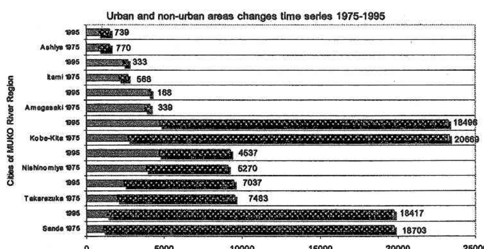

Fig. 9 Urban / non-urban changes in Muko River Region

4. ANALYSIS MODELS AND SIMULATION SYSTEM

As various data are used for environmental impacts estimation, GIS-based modeling and simulation system is constructed. The system is composed of three modules as shown in Fig. 10; database, models setting and simulation, and results display for the outputs of the data modeling and simulation system. Environmental impact elements attributable to management policies are identified and land use/land cover changes (LUCC) and activities are analyzed in the Region in order to direct the future development polices, plans and strategies to the environmental management[6].

4.1 GIS-Based Analysis Models in Muko River Basin Region

GIS-based analysis models are constructed for environmental changes assessment and related impacts estimation in suburbanized urban areas of Muko River Basin Region. Data for the regression models are established in GIS 1km grid for suburbanized areas and the urban activities in the Region to be analyzed.

(1) Analysis Methodology

The analysis process depends on studying the correlation of changes of urban areas and suburbanization activities in the Region with several explanatory variables regressed by the models. The models study the relation between the growth of population and urban areas and related environmental impacts in the Region. First step of the analysis is to establish "regression models" to explain the correlation of the environmental changes with several explanatory variables including population, urban activities and other variables. Secondly, is to calculate the environmental loads such as CO_2 emissions, which are regressed by parameters of the analysis and other statistics for outputs simulations.

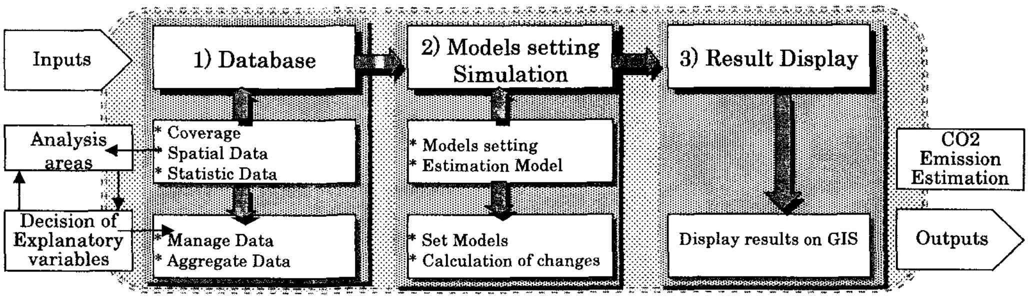

Fig. 10 Estimation Process and Simulation System of Environmental Impacts Assessment in Muko River Basin Region

(2) The Urban Regression Model

The urban regression model designed for studying the urban activities and suburbanization effects in Muko River Region, Fig.7 shows urban areas changes in 1km grid map between 1975s and 1995s in the Region. The model explain the correlation of urban areas changes with several explanatory variables including population, urban land use categories such as residential, commercial areas, industrial and other urban facilities, as shown in Eq.1. The urban areas in the model are inked to population (P), residential areas (R), and urban activities factors (A), which lead to the growth of urban area and drive the urban expansion and related impacts, where (U) is total urban area in the zone of analysis.

$$U = \alpha_0 + \alpha_1 \sum_i^k \frac{P_i R_i}{L_i} + \alpha_2 \sum_i^k \frac{P_i A_i}{L_i} \qquad (1)$$

where

U : total urban area of the urban zone

Pi : total population of the grid i

Ri : the residential area in the grid i

Ai : total urban activities in grid i

Li : total land of grid i (urban and non-urban)

i : the grids No. from 1 to k

The expansion of urban activities in the Region between 1975s and 1995s are analyzed based on the regressions in Eqs. 2, 3. R and R^2 of the regressions for the two decades give a strong correlation between urban change and related explanatory variables regressed by the model, which give the factors of the expansion of suburbanized areas in the Region. Table 1 shows the estimation results of the regression analysis for time series changes.

$$U(t_0)_{1975} = \alpha_0 + \alpha_1 \sum_i^k \frac{P_i R_i}{L_i} + \alpha_2 \sum_i^k \frac{P_i A_i}{L_i} \qquad (2)$$

$(R = 0.87,\ R^2 = 0.75)$

$$U(t)_{1995} = \alpha_0 + \alpha_1 \sum_i^k \frac{P_i R_i}{L_i} + \alpha_2 \sum_i^k \frac{P_i A_i}{L_i} \qquad (3)$$

$(R = 0.79,\ R^2 = 0.63)$

The changes of urban areas for time series between 1975s and 1995s in the selected zones in Muko River Basin Region are estimated using the following Eq. (4)

$$\Delta U = U(t)_{1995} - U(t_0)_{1975} \qquad (4)$$

Table 1. Estimation results of the regression

Variable	Coefficient estimate 1975	Coefficient estimate 1995
Constant	528.442	912.925
X1	0.008	0.015
X2	0.025	0.043
Zone 1	-1.467	-0.957
Zone 2	-0.030	-0.291
Zone 3	-0.178	0.130
Zone 4	1.679	1.848
Zone 5	0.317	-0.179
Zone 6	-0.026	-0.859
Zone 7	-0.266	0.307
R	0.87	0.79
R^2	0.75	0.63
t. value	2.024	0.919

(3) The Sales Regression Model

The sales regression model is designed to explain the correlation of sales amount (*S*) with several explanatory variables including population (*P*), retail floor space (*R*), trip distance and time length from residential area surrounding commercial areas (*d*). The relationship between sales changes, population growth, retail development, time distance reduction and related CO_2 emission changes are analyzed and data are simulated for CO_2 emission and factors relation. Carbon dioxide emission and its changes for three decades are estimated by designing the analysis regression model and simulation system for CO_2 calculation and analysis of emission changes in Muko River Basin Region.; Fig.8 shows sales changes between 1975s and 1995s.

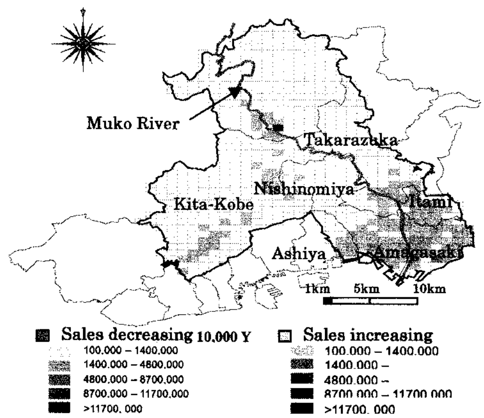

Fig. 11 Sales changes in Muko Region between 1975 and 1995

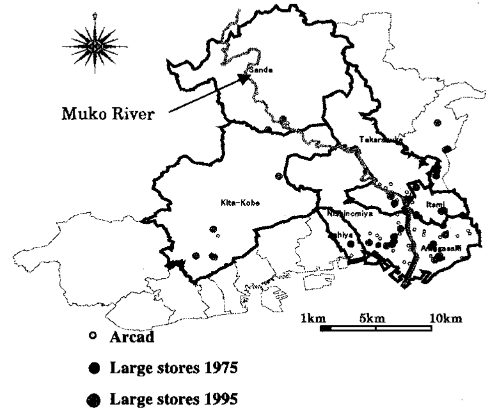

Fig. 12 Muko Region Boundaries and commercial classification

The commercial areas in the Region are classified into two major categories namely, large scale stores, and arcades, as shown in Fig. 9. The analysis focuses on studying the grid areas, which include such categories and related CO_2 emission levels change between 1975s and 1995 as an influenced area by automobile trips for shopping from surrounding residential areas within buffer zone of 10km and 15-20 min accessibility time.

$$S_i = \alpha_0 + \alpha_1 \left(\sum_{j=1}^{k} \frac{P_j R_i}{d_{ij}^2} \right) \tag{5}$$

where

S: sales (10,000 Yen)
k: grids from 1 to k around retail grid
P_j: population in grid j (person)
R_i: retail floor space in grid I (m2)
D_{ij}: time distance between i and j (min)

The sales changes of commercial areas between 1975 and 1995 are analyzed using the regressions in Eqs 6 and 7. R and R^2 of the regressions give strong correlations of sales with the related explanatory variables. The sales amount in the model is inked to several factors, which lead to the changes of sales and drive the related impacts of shopping trips.

$$S_i(t_0)_{1975} = \alpha_0 + \alpha_1 \left(\sum_{j=1}^{k} \frac{P_j R_i}{d_{ij}^2} \right) \tag{6}$$

$(R = 0.88, R^2 = 0.77)$

$$S_i(t)_{1995} = \alpha_0 + \alpha_1 \left(\sum_{j=1}^{k} \frac{P_j R_i}{d_{ij}^2} \right) \tag{7}$$

$(R = 0.86, R^2 = 0.74)$

The changes of sales between 1975 and 1995 are given by the following Eq. (8), which indicated that sales amount increased in some areas in the region. The regression results are used as inputs for the simulation model to calculate CO_2 emission. Table 2 shows the estimation results of the regression.

$$\Delta S_i = S_{i(t)_{1995}} - S_{i(t_0)_{1975}} \tag{8}$$

Table 2 Estimation results of statistics regression

Case	Coefficient estimate 1975	Coefficient estimate 1995	Case	Coefficient estimate 1975	Coefficient estimate 1995
Constant	252249.26	630877.3	Zone 19	1.043	-1.047
Zone 1	0.253	-0.333	Zone 20	1.095	0.503
Zone 2	0.694	-1.179	Zone 21	-0.357	1.932
Zone 3	1.626	-0.052	Zone 22	-0.797	1.343
Zone 4	-0.175	-0.939	Zone 23	-0.368	1.979
Zone 5	0.618	-0.744	Zone 24	-0.781	1.167
Zone 6	-0.041	-0.815	Zone 25	-0.727	0.917
Zone 7	-2.798	-0.452	Zone 26	-0.813	-0.948
Zone 8	0.321	-1.195	Zone 27	2.736	1.411
Zone 9	-0.789	-0.016	Zone 28	0.632	0.762
Zone 10	0.641	-2.415	Zone 29	-0.615	0.955
Zone 11	-0.530	-0.577	Zone 30	-0.818	-1.175
Zone 12	-0.630	-0.116	Zone 31	1.361	-0.019
Zone 13	-0.587	0.147	Zone 32	-0.172	-0.928
Zone 14	-0.004	1.233	Zone 33	-0.735	0.885
Zone 15	-0.923	0.379	R	0.88	0.86
Zone 16	-0.387	0.356	R2	0.77	0.74
Zone 17	1.821	-0.594	t value	3.731	5.493
Zone 18	-0.275	-0.710			

4.2 GIS-based Assessment of CO_2 Emission in Muko River Basin Region

Emission of Carbon dioxide and its changes between 1975s and 1995s caused by automobile trips to commercial areas in the Region are estimated by designing CO_2 calculation model and simulation system based on the outputs of the regression models, as shown in Eq. (9). The impacts of CO_2 emission are divided into three main factors namely; suburbanization increasing impacts, population increasing impacts, and shopping related impacts.

(1) CO2 Calculation Model and Simulation System

The CO_2 emission in the shopping areas, which caused by automobile shopping trips is recognized as one of the most serious urban problems in the Region as a result of urban areas expansion, and suburbanization effects. The outputs of the regression are simulated for estimating CO_2 emissions based on the rate of car using density from all traffic 28.7% for 1975, and 38.4% for 1995[8] (Road traffic census 1977, 1997).

$$Y_{ij} = \left(S_i \times 10^4 \left(\frac{a \times \frac{P_j R_i}{d_{ij}^2}}{a \times \sum_{j=1}^{k} \left(\frac{P_j R_i}{d_{ij}^2} \right)} \right) \right) \times \left(\frac{1}{E} \right) \times A \times L_{ij} \times U \times \frac{1}{10^6} \qquad (9)$$

where:

Y_{ij}: the amount of CO2 exhausts (t-CO2)
S_i: annual sales of grid i (10,000 Yen)
P_j: population of grid j (person)
R_i: retail floor space of grid i (m2)
d_{ij}: time distance from grid I to grid j(min)
k: grids No. from 1 to k around retail grid
E: living expenditure for one time shopping trip (Yen/person)
A: automobile rate from all transportation
L_{ij}: distance length from i to j (km)
U: CO2 exhaust unit (g-CO2/person "km

The car average speed zones on road accessibility to retail areas in grid (i) from surrounding residential areas in grid (j), which used for time distance calculation (d_{ij}) from grid j to i, are divided into two major zones in the Region as shown in Table (3). The CO_2 emissions caused by automobile shopping trips in the Region are calculated based on the model shown by Eq. (9). Changes of CO_2 emissions in the suburbanized areas in the Region for time series between 1975s and 1995s are estimated using the Eq. 10.

$$Y_{ij}\ changes = Y_{ij}(t) - Y_{ij}(t_0) \qquad (10)$$
$$Y_{ij}(t - t_0) = Y_{ij}(1995) - Y_{ij}(1975)$$

where:

Y_{ij}: the amount of CO2 exhausts (t-CO2)
t: time of estimation

Table 3 Average speed of cars in Muko River Basin Region areas (km/h) *

Area zone	1977	1997
South-Hanshin area NISHINOMIYA, TAKARAZUKA	**29.3**	**22.9**
North-Hanshin Area (SANDA, KOBE-KITA,NORTH NISHINOMIYA)	**40.6**	**44.1**

*Road traffic census (1977, 1997)[8]

Table 4 Changes of CO2 emission around commercial areas on Muko River Basin from 1975s t0 1995s

CO2 emission level (t/km2)	Emission in 1979/1km grid No. of grids	%	Emission in 1995/1km grid No. of grids	%
1- 100	20	58.82	16	47.06
100 - 200	6	17.65	8	23.53
200 - 300	3	8.82	6	17.65
300 <	2	5.88	3	8.82
Total	31	100	33	100

5. RESULTS AND DISCUSSION

The regression model for sales changes analysis and CO_2 calculation model estimated that CO_2 emission rate caused by automobile trips for shopping is increased 1.3 times from 1975s, to 1995s. The outputs results of the analysis are displayed on GIS for CO_2 emission changes between 1975 and 1995 as shown in Figs13 and 14. The results of the comparative analysis for CO_2 estimation between 1975 and 1995 indicate that the increase of CO_2 emissions caused by increasing of automobile trips to shopping areas as shown in Figs. 13, 14 and 15. CO_2 emission rate in the commercial zones of levels ranged from 100-200 t-CO_2 increased from 6 to 8 zones, for levels from 200-300 t-CO_2 increased from 3 to 6 zones and levels more than 300 t-CO_2 increased from 2 to 3 zones, as given in Table 4 and Fig. 15 which show the changes of emission rate between 1975s and 1995s in the Region.

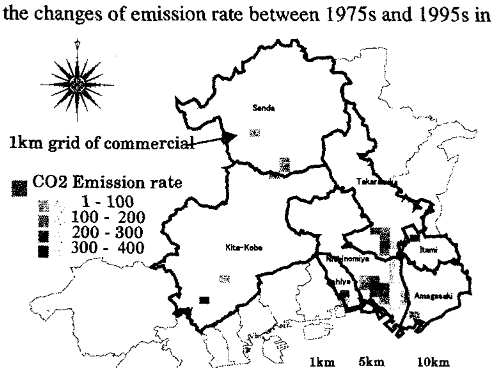

Fig. 13 CO2 emission rates around shopping areas in 1975

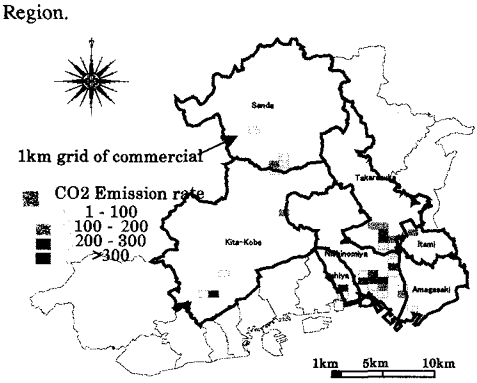

Fig. 14 CO2 emission rates around shopping areas in 1995

The results of the regressions and the comparative changes analysis indicate that the areas where CO_2 emissions increase are significantly increasing in population in Kita-Kobe, the southern Nishinomiya and southern Takarazuka. The results indicate that CO_2 emission from commercial areas increased about 1.3 times in the whole region (3526.26 t. in 1975) and (4584.04 t. in 1995). Although sales amount in some commercial areas are decreasing for the time series between 1975s and 1995s, the emissions of CO_2 caused by automobile shopping trips are still increasing.

It is considered to be as a result of increasing the consumption potential by growth of population in the suburbanized areas in the Region.

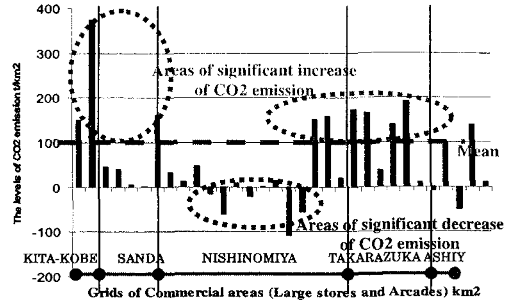

Fig. 15 CO_2 emission rates changes around shopping areas for time series between 1975s and 1995

6. CONCLUSION

The results of the comparative analysis for changes between 1975s and 1995s, and data simulation indicate that the environmental loads are increasing by growth of population and suburbanized activities. The growth of population and urban activities resulted in expansion of suburbanized areas and loss of natural areas and other related environmental impacts. The expansion of suburbanization areas and activities resulted in increasing CO_2 emission rate about 1.3 times by automobile shopping trips. CO_2 emission increased in suburbanized areas as a result of retail area density distribution of commercial areas in the region.

The results of the regression and simulation guide to key factors for policy recommendations for the future sustainable development, and environmental management in the regional scale:

1) The need to plan for urban activities and density distribution control of services areas in order to reduce the environmental loads in the regional scale.
2) The expansion of suburbanized areas in the region guides to plan for reducing time distance from residential areas to the other urban areas in order to reduce CO_2 emissions by automobile trips.
3) The urgency of the need to reduce CO_2 emission in urban areas may grant and guide to control the retail areas growth and to direct the development plans and strategies for growth management, and urban activity control.

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