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Full Paper

GIS-BASED ASSESSMENT OF CO_2 EMISSION CAUSED BY AUTOMOBILE TRIPS FOR SHOPPING, CASE STUDY IN MUKO RIVER BASIN REGION

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Abstract

This paper estimates CO_2 emission caused by automobile trips for shopping in Muko River Basin region. The analysis was carried out utilizing 1km grid GIS and statistical data for land use, population, commercial, and other data focusing on areas where CO_2 emission by automobile trips was most serious. Comparative analysis between 1975 and 1995 was carried out by first establishing "sales regression model" to explain the correlation of sales changes with selected explanatory variables, and then "CO_2 emission calculation", which was regressed by parameters of the analysis and other statistics. The results showed significant impact of automobile shopping trips oriented CO_2 emission on the property value.

Keywords: *GIS, CO_2 emission, Automobile shopping trips, Suburbanization, Environmental impacts*

1. Introduction

The rapid urbanization and high diversified developments of urban areas and urban facilities in Japan, after World War II, has brought much social efficiency and has led to occurrence of pollution in areas of large-scale urban facilities, such as commercial, industrial and residential urban areas (Environment Agency, 1995, Srinivas, 2004). The growth of suburbanization activities and economics in Muko River Basin (MRB) region, Hyogo Prefecture, Japan, starting from 1950s, has resulted in several environmental impacts such as air pollution, water contamination, waste generation, CO_2 emission, and other impacts (Khaled et al., 2003a).

This paper attempts to estimate CO_2 emission caused by urban expansions and suburbanized urban activities growth. MRB region, Hyogo Prefecture, a west part of Kansai Metropolitan region, Japan, was selected as a case study for the CO_2 emission caused by automobile trips for shopping. Site significant effects of economic growth and urban expansions were found in the region. The commercial activities are experiencing dramatic growth in the region and resulting in considered environmental changes with related impacts. The population, socio-economic activities data and their changes between 1975 and 1995 were analyzed by making effective use of available statistical data and other coverage in the region integrating with GIS 1 km grid database system. Suburbanized area expansions of cities surrounding MRB, and current environmental changes affected by the growth of commercial activities in the region were analyzed and related CO_2 emissions were estimated.

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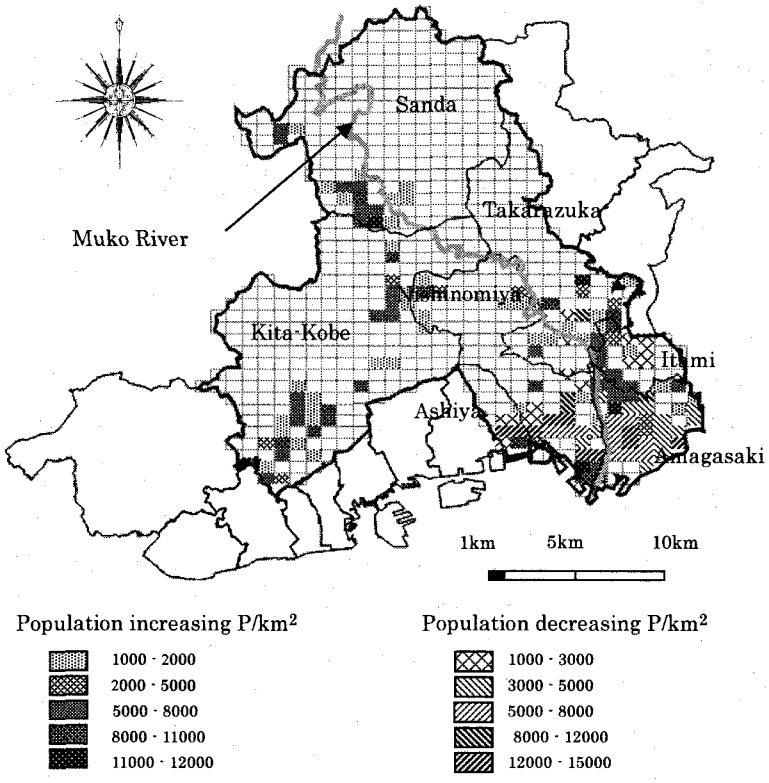

Fig. 1 Population changes in Muko River Basin (MRB) Region between 1975 and 1995

2. Methodology

2.1 Data Set Processing

The population in MRB region increased from 1.5 million in 1975 to 1.7 million in 1995 (Hyogo Prefecture, 2003), (Fig. 1). The increase in infrastructure and railway construction, and development of automobile expressways network have resulted in urban expansions and suburbanized activities growth which consequently caused a lot of global environmental emissions such as CO_2, local contaminations, natural loss of forests and greens, and other environmental impacts (Fujita et al., 2003, Morioka and Fujita, 2003). GIS-based analysis was established to estimate CO_2 emission caused by development of urban facilities and increasing of automobile shopping trips in the region based on a comparative analysis between 1975 and 1995. Emissions of CO_2 brought by expansion of suburbanized urban areas and activities, and increase of automobile access to shopping areas were identified utilizing 1 km GIS grid data.

The analysis was carried out based on these data of population and commercial activities in suburbanized areas of Nishinomiya, Takarazuka, Kita-Kobe, Sanda, Itami, Amagasaki, and Ashiya cities in MRB region. Figure 2 shows the boundaries of these cities and classification of their commercial patterns in the region.

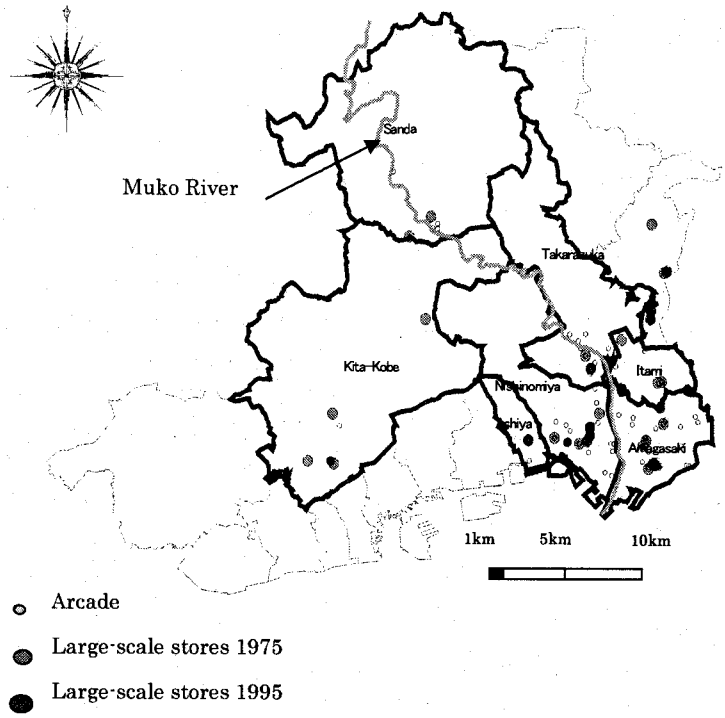

Fig. 2 Boundaries of MRB Region and commercial areas classification

An integrated 1 km grid GIS-statistical data base system was established for changes comparative analysis in MRB region. The system was obtained using various categories and types of regional statistical and spatial GIS data such as land use, transportation network, automobile trips time distance, and population allocation (Hyogo Prefecture, 2003). Social activities data and other coverage data for the study area such as commercial sales amount, and large-scale stores allocation were converted into 1 km grid (1km^2) data, as well as transportation accessibility of automobile ways in this region (Statistics Bureau, 2003, National Land Planning Office, 2002).

The data were subjected to regression and comparative analysis between 1975 and 1995 for assessing CO_2 emission changes and related factors. The commercial areas were classified into two major categories; a) large-scale stores (supermarkets), and b) arcades (the traditional shopping areas). These data of commercial allocation were converted into 1 km GIS grid data as shown in Fig. 2.

The data-base system included various types and categories of data sources and other coverage data, which were considered in the analysis and included the following:

(A) 1 km grid GIS spatial data for population, commercial, land use, (Hyogo Prefecture, 2003).
(B) Statistical 1 km grid data for the period between 1975 and 1995, (Hyogo Prefecture, 2003).
(C) Japan Statistical Yearbook Data, (Statistics Bureau, 2003).
(D) Road Traffic Census data in the region for the years 1977 and 1997, (Transport Energy, 2002, National Land Planning Office, 2002).
(E) Other related coverage data and maps.

2.2 Estimation Process of CO_2 Emission

As various data were used for the estimation and comparative analysis, GIS-based simulation system was constructed for CO_2 emissions estimation. The system was composed of three main modules; a) database establishing, b) models setting and simulation, and c) results displaying for the outputs of data modeling and simulation (Kitano et al., 2001), as shown in Fig. 3. Environmental impact elements attributable to management policies were identified and suburbanized areas and commercial activities changes in the region were analyzed in order to direct the future development polices to the environmental management, impacts reduction, and sustainable development (Khaled et al., 2003d).

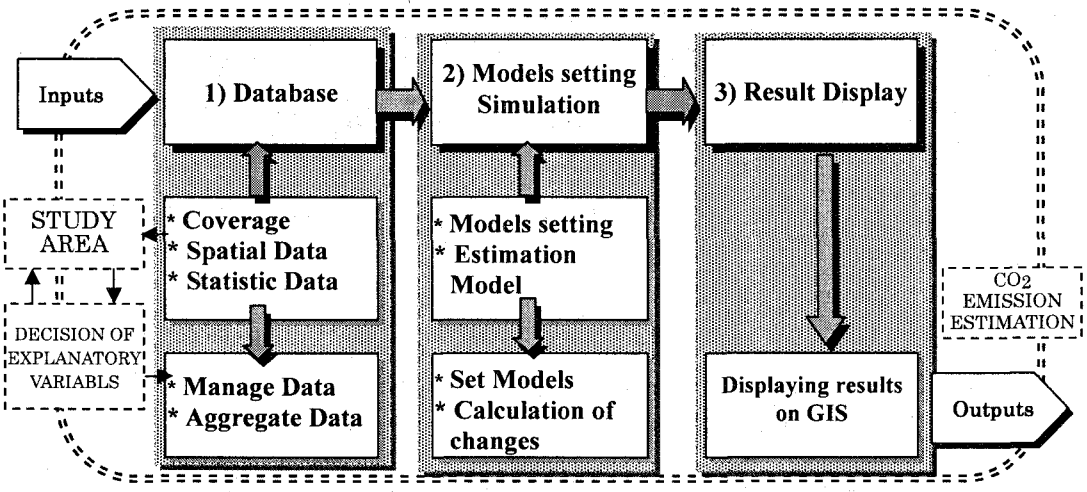

Fig. 3 CO_2 estimation process and simulation system in MRB Region

(1) GIS-Based Assessment of CO_2 Emission

Regarding the changes in suburbanized activities of MRB region, a GIS-based analysis was established in 1 km grid data for suburbanized areas and commercial activities to be analyzed. CO_2 emission and its changes for two decades between 1975 and 1995 were estimated by designing the calculation model for CO_2 emission based on the results of sales regression model (Khaled et al., 2003b). The impacts of CO_2 emission were linked to three main factors namely; a) suburbanization increasing impacts, b) population increasing impacts, and c) shopping related impacts.

(2) Analysis Methodology

The analysis process focused on studying the correlation of sales amount changes and automobile trips generation to shopping areas based on time distance changes between origins and destinations of commercial use. The analysis focused on studying the grid areas, which include the commercial use and related CO_2 emission changes between 1975 and 1995. The commercial areas were taken as destinations for automobile trips from surrounding areas within buffer zone of 8-10 km. These zones were built based on the suitable auto accessibility riding time for about 15-20 min. for automobile shopping trips by surrounding residences. The grid areas of commercial use were selected as influenced areas for estimating CO_2 emissions caused by automobile trips for shopping in the region.

2.3 Models of the Analysis

(1) Sales Regression Model

The change of sales annual amount in MRB region between 1975 and 1995 was given for each grid by the Eq. 1 which indicated increase in the annual amount of sales in some commercial areas in the region, (Fig. 4). These changes were used for analyzing related effects of automobile trips for shopping to these commercial areas from surrounding residential areas in the selected buffer zones.

$$\Delta S_i = S_{i(t)} - S_{i(t_0)} \tag{1}$$

where:

S_i: sales amount in grid i (10,000 Yen)

(t_0) = 1975, and (t) = 1995

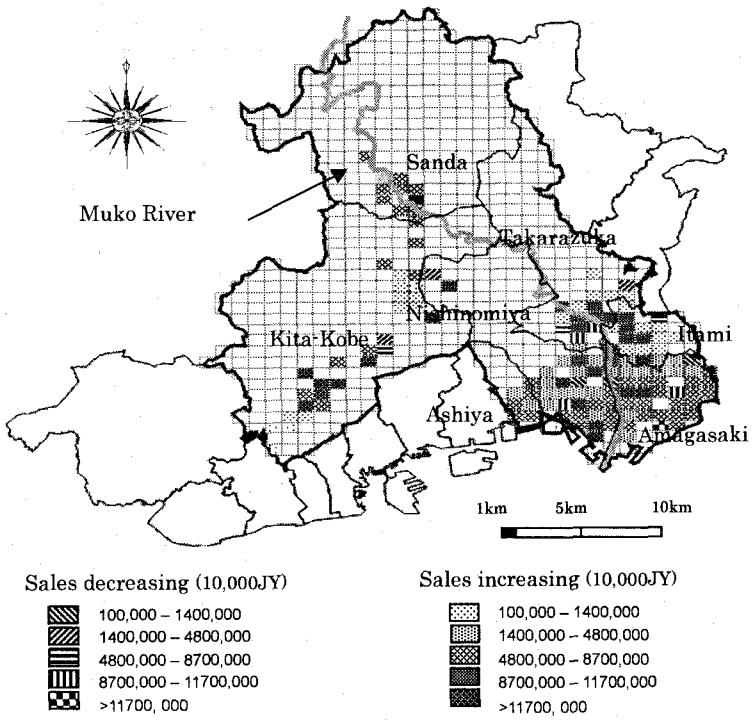

Fig. 4 Sales changes in MRB Region between 1975 and 1995

Figures 5 and 6 show the locational distribution of the large-scale stores which was transformed to GIS from the latitude and longitude geographic data inputs in 1976 and 1996 based on Japanese Statistical Yearbook data. The changes between 1975 and 1995 which were displayed in these figures reflected increase the commercial areas of large-scale shopping centers in the region. The commercial area was defined basically for areas of large-scale stores even if not included the traditional shopping areas of arcades, and commercial grid was that which included the commercial use of one or both sectors, while commercial zone was the selected buffer zone of analysis around the commercial grid.

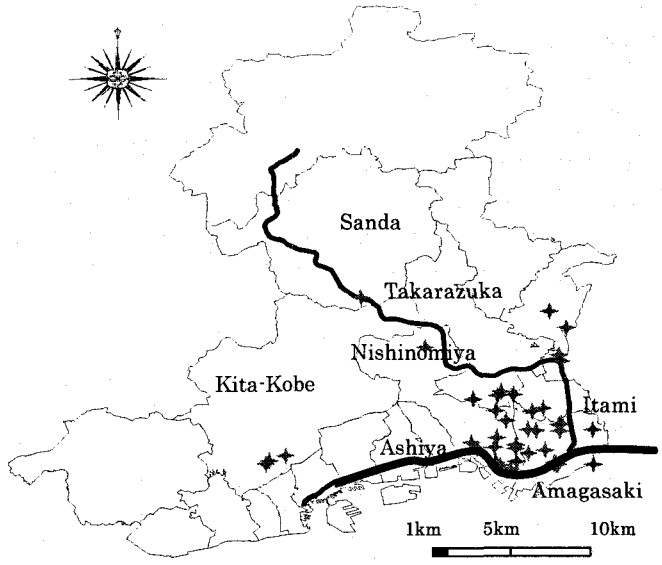

Fig. 5 Large-scale stores locations in MRB Region 1975

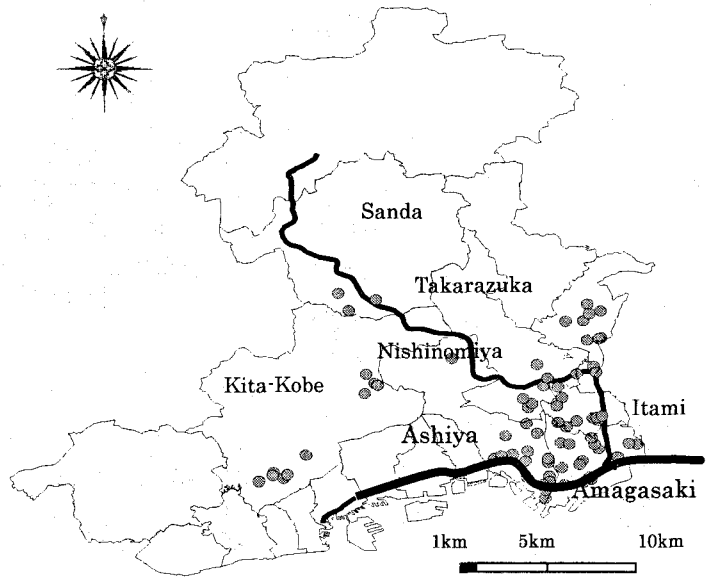

Fig. 6 Large-scale stores locations in MRB Region 1995

Sales regression model was applied to explain the correlation of sales amount for each grid of commercial use with selected explanatory variables set including population, retail floor area of the large-scale stores, and the estimated time distances for automobile trips between origins of residential areas and destinations of commercial areas, which indicated the related impacts of CO_2 emissions (Robert et al., 1991, Robert and Samuel, 1983). The estimation results of sales regression with these selected variables were given for the analysis in the area of 8-10 km buffer zone around the commercial areas for automobile trips for shopping to retail centers for each city in the region.

The model was constructed based on the GIS estimated data for the 33 grids which contain commercial areas of large-scale stores within the selected buffer zones for the analysis. The model studied the correlation of sales amount in grids which include commercial areas with these explanatory variables within the selected zones as shown in Eqs 2. The sales annual amount in these commercial areas was analyzed for the period between 1975 and 1995 using the regressions as shown in Eqs. 3 and 4, where annual sales amount was linked to the selected explanatory variables set of population P_j of grids around commercial grids (origins) within the selected buffer zone, retail floor area R_i of grids which include commercial use (destinations), and time distances d_{ij} between origins and destinations of commercial area of grid i.

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

where:
S_i: sales amount in grid i (10,000 Yen)
k: grids No. from 1 to k
P_j: population in grid j (person)
R_i: retail floor area in grid i (m^2)
d_{ij}: time distance between i and j (min)

The correlation coefficients R & R^2 of this regression in 1975 and 1995 reflected the strong correlation between sales amount and the explanatory variables set used in the model, which were *($R = 0.88$, $R^2 = 0.77$)* for the estimation in 1975, and *($R = 0.86$, $R^2 = 0.74$)* for the estimation in 1995, as shown in Eqs. 3 and 4. These variables, which were used in these regressions and showed strong correlation with sales amount change in the region, were used as inputs for the calculation of CO_2 emissions caused by automobile shopping trips for the period of analysis between 1975 and 1995.

$$S_{i(t_0)} = \alpha_0 + \alpha_1 \left(\sum_{j=1}^{k} \frac{P_j R_i}{d_{ij}^2} \right) \tag{3}$$

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

$$S_{i(t)} = \alpha_0 + \alpha_1 \left(\sum_{j=1}^{k} \frac{P_j R_i}{d_{ij}^2} \right) \tag{4}$$

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

where:
S_i: sales amount in grid i (10,000 Yen)

(t_0) = 1975, and (t) = 1995

The estimation results of the statistics regressions for the coefficients $\alpha 0$ and $\alpha 1$ of the correlation between sales amount and the selected explanatory variables set were shown in Figs. 7 and 8 and reflected the strong correlation between sales amount and the selected explanatory variables set in the regression for 1975 and 1995.

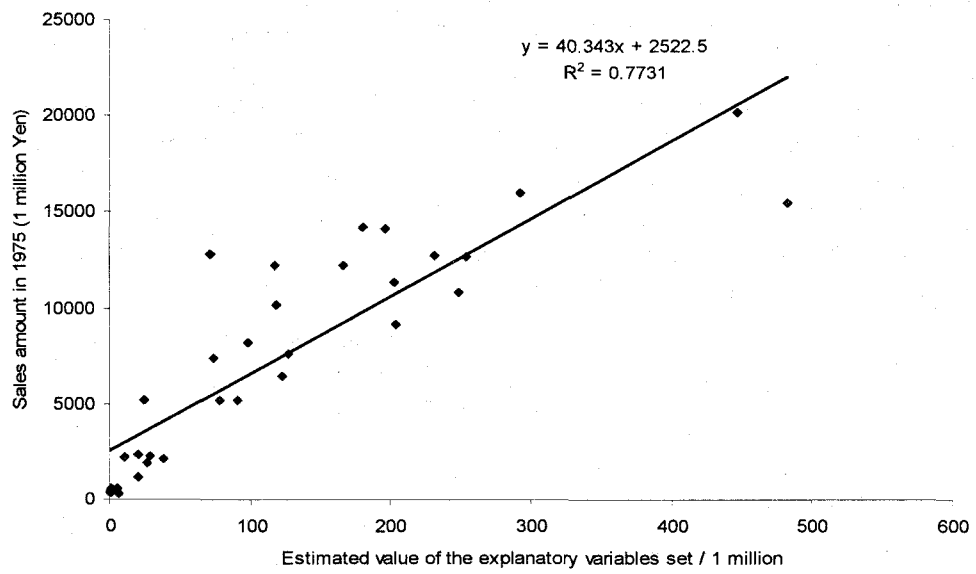

Fig. 7 Regression line for the correlation between sales amount and selected variables in 1975

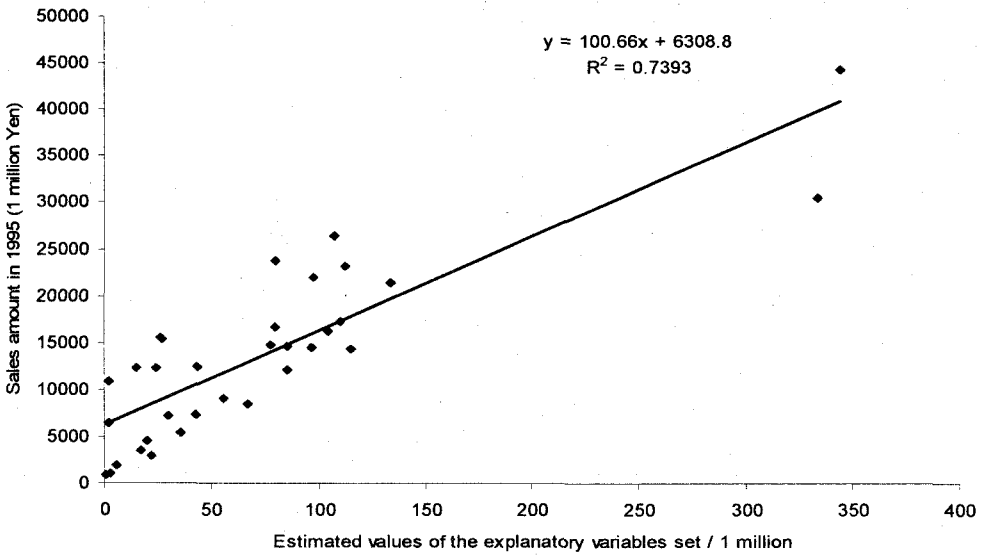

Fig. 8 Regression line for the correlation between sales amount and selected variables in 1995

Figures 7 and 8 show the regression lines of the correlation between sales and selected explanatory variables set for the period between 1975 and 1995 for the regressions shown by Eqs. 3 and 4 which reflected the strong correlation between sales and the selected variables used for each grid of the commercial use within the selected buffer zones in the region. The t-statistics test was significant for the selected variables of the regression for the two samples of 1975 and 1995 at the 0.01 level.

(2) CO_2 Calculation Model

The CO_2 emission in the selected grids included the large-scale shopping centers, which caused by automobile trips from areas within the selected buffer zones around these commercial areas, was recognized as one of the most serious urban environmental problems in the region as a result of the growth of suburbanized areas and economic activities. The automobile trips for shopping were calculated from the origin of surrounding areas to these grids which included the areas of commercial use within the selected buffer zones. The explanatory variables set which showed the strong correlation in sales regression analysis for the period of analysis between 1975 and 1995 in these grids of commercial use was used as inputs for the CO_2 emission calculation using the estimation model shown in Eq. 5.

$$Y_{ij} = \left(S_i \times 10^4 \left(\frac{\frac{P_j R_i}{d_{ij}^2}}{\sum_{j=1}^{k} \left(\frac{P_j R_i}{d_{ij}^2} \right)} \right) \right) \times \left(\frac{1}{E} \right) \times A \times L_{ij} \times U \times \frac{1}{10^6} \quad (5)$$

where:

Y_{ij}: the amount of CO_2 exhausts (t- CO_2)

S_i: annual amount of sales in grid i (10,000 Yen)

P_j: population in grid j (person)

R_i: retail floor area in grid i (m^2)

d_{ij}: time distance from grid i to grid j (min.)

k: grids No. from 1 to k

L_{ij}: distance length from i to j (km)

E: living expenditure for one time shopping trip per person (Yen/person)

A: modal share of automobile (%)

U: CO_2 exhaust unit (g-CO_2/person "km)

Taking the modal share of automobile using density from all traffic as 28.7% for 1975, and 38.4% for 1995 based on Road Traffic Census for 1977, and 1997, (Transport Energy, 2002, National Land Planning Office, 2002). The car average speed on road accessibility to shopping areas in grid (i) from surrounding residential areas in grid (j), which was used for time distance calculation (dij) from grid j to grid i, were divided into two major zones for the analysis in this region and shown in Table 1.

Table1. Average speed of cars in MRB Region (km/h) *

Area zone	1977	1997
South-Hanshin area Nishinomiya, Takarazuka	29.3	22.9
North-Hanshin Area (Sanda, Kobe-Kita, North of Nishinomiya)	40.6	44.1

*Road Traffic Census (Transport Energy, 2002, National Land Planning Office, 2002)

Changes of CO_2 emissions caused by automobile trips for shopping activities from origins of residential areas to destinations of commercial areas for the period between 1975 and 1995 in suburbanized areas of the region were estimated based on the regressed variables and others parameters showed by the calculation model in Eqs. 5 and 6. The estimation results of CO_2 emissions as shown in Table 2. CO_2 emissions change results in the region were displayed on GIS as shown in Figs. 9 and 10, which reflected the increase of CO_2 emissions.

$$\Delta Y_{ij} = Y_{ij\,(t)} - Y_{ij\,(t_0)} \tag{6}$$

where:

Y_{ji}: the amount of CO_2 exhausts (t- CO_2)

$(t_0) = 1975$, and $(t) = 1995$

Table 2 Changes of CO_2 emission in grids of commercial use in MRB Region between 1975 and 1995

CO_2 emission level (t/ km²)	Emission in 1979/km²		Emission in 1995/km²	
	No. of grids	%	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

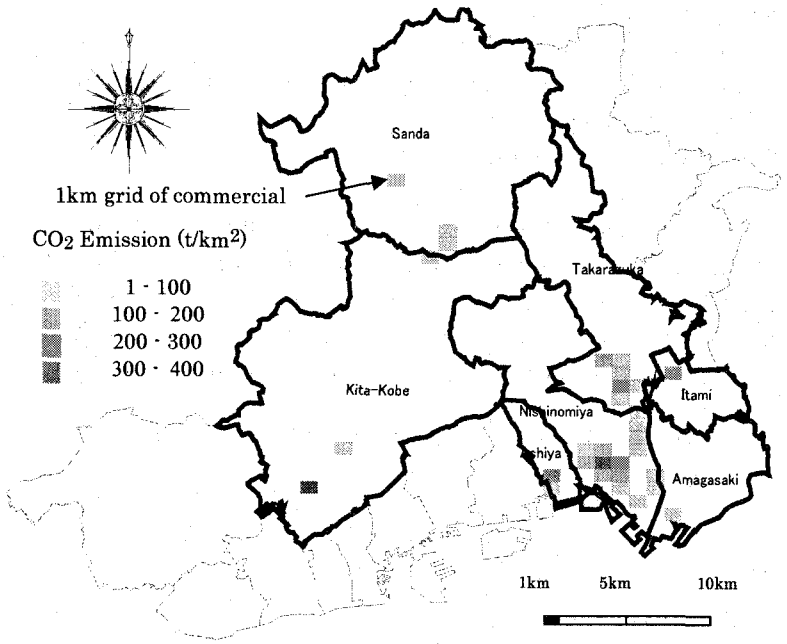

Fig. 9 CO_2 emissions in the grids of commercial use in MRB Region in 1975

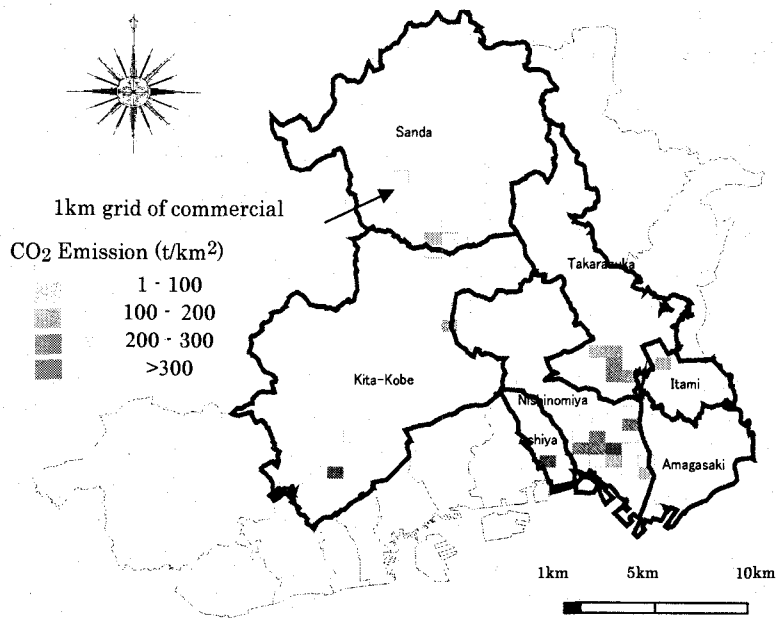

Fig. 10 CO_2 emissions in the grids of commercial use in MRB Region in 1995

Figures 9 and 10 show the simulation output results as displayed on GIS for CO_2 emissions caused by automobile trips for shopping activities to the commercial areas of large-scale stores in the region for the period of analysis between 1975 and 1995, which reflected the increase of CO_2 emissions in the region (Khaled et al., 2003d). Figure 11 shows the output results of the CO_2 emission changes for the period of analysis between 1975 and 1995 in the region in the selected grids which included the commercial use within the selected buffer zones.

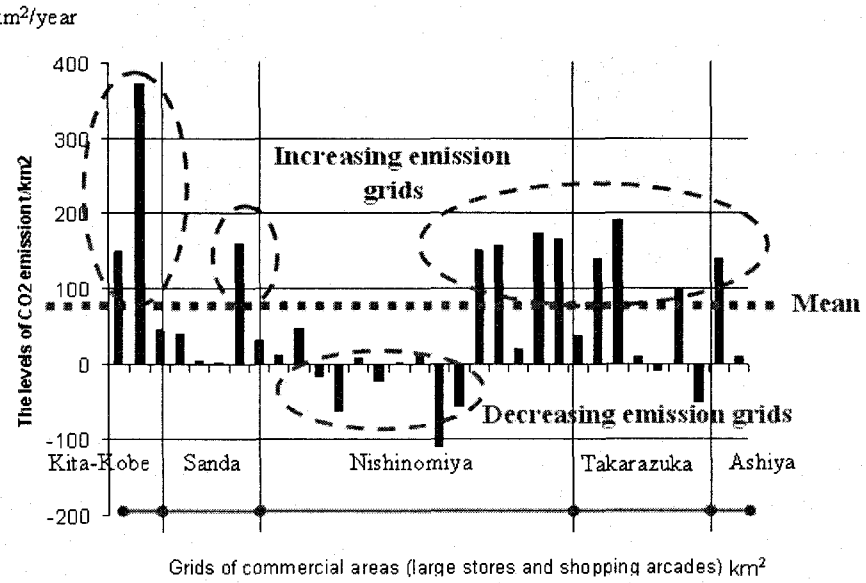

Fig. 11 CO_2 emission changes in the grids of commercial use between 1975 and 1995

3. Results and Discussion

The GIS based regression model for sales change analysis and CO_2 calculation model estimated the CO_2 emissions caused by automobile trips for shopping to the commercial areas for the period of analysis between 1975 and 1995 in MRB region. The results of the analysis were displayed on GIS as shown in figs 9 and 10. The results of the comparative analysis for changes of CO_2 emissions gave the indicators of increasing values of CO_2 emissions caused by the automobile trips to shopping areas for the period of analysis between 1975 and 1995.

The results shown in Fig. 11 indicated that commercial grids of CO_2 emission level ranged from 100-200 t-CO_2 increased from 6 to 8 grids, for emission level ranged from 200-300 t-CO_2 increased from 3 to 6 grids, and for level more than 300 t-CO_2 increased from 2 to 3 grids, (Table 2).

The simulation results indicate that the CO_2 emission in the whole region increased as a result of increasing the population, sales and shopping activities, (Fig. 12). The regression and simulation results showed the strong correlation between changes of sales activities and changes of the selected explanatory variables set of population, retail floor area, and time distances of automobile trips for shopping, which resulted in the change of CO_2 emission generated by increase in the sales activities and automobile trips for shopping in the commercial grids within selected buffer zones in the region.

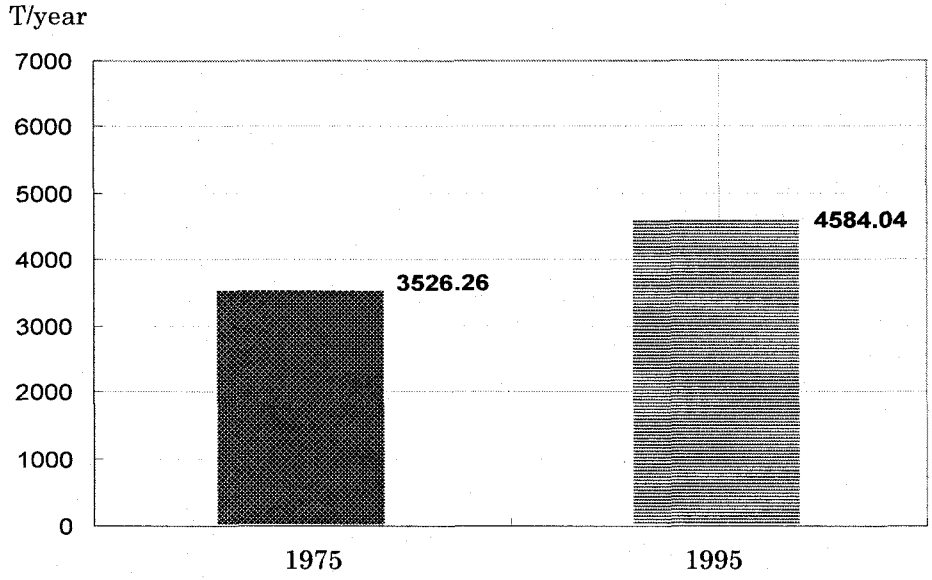

Fig. 12 Total CO_2 emission changes between 1975 and 1995 in MRB Region

The suburbanized area expansions, retail area density distribution and centralization of commercial areas with long automobile trip distances resulted in increasing CO_2 emission generated by automobile trips for shopping in the region, which guide to plan for reducing the time distance from the residential areas to these commercial areas in order to reduce the automobile trips for shopping with related CO_2 emissions.

The urgency of the need to reduce CO_2 emission in urban areas may grant and guide to control the direction of the retail areas and urban areas growth, and to direct the development plans and strategies for urban growth management, and CO_2 reduction (Michael, 1999).
The results of the calculation model and changes estimation of the comparative analysis in (MRB) region indicated that the areas where CO_2 emissions increased were those where there was a significant increase in population in Kita-Kobe, the southern areas of Nishinomiya and Takarazuka. The results indicated that CO_2 emission from commercial activities increased about 1.3 times in the whole region from 3526.26 t in 1975 to 4584.04 t in 1995, (Fig. 12).

The output results and findings of the comparative analysis for changes between 1975 and 1995, and estimation of CO_2 emission caused by automobile trips for shopping activities growth in the region were summarized as follows (Khaled et al., 2003c):

1) Significant environmental loads and impacts were found in the region caused by automobile trips for shopping and growth of suburbanized activities and economic in MRB region for the period between 1975 and 1995.
2) The cycle relation of increasing the environmental impacts of air pollution and CO_2 emission with the growth of population, socio-economic activities and suburbanized areas expansions as major driving forces for changes in the region.
3) The results of changes analysis indicated that the areas where the increase of CO_2 emissions caused by automobile trips for shopping were significantly increasing in population for southern areas of Kita-Kobe city and Sanda city, and the southern areas of Nishinomiya and Takarazuka.
4) The results indicate that CO_2 emissions caused by shopping trips to commercial areas increased about 1.3 times in the whole region from 3526.26 t (1975) to 4584.04 t (1995).
5) Although sales amount in some commercial areas was decreasing during the period between 1975 and 1995, emissions of CO_2 caused by automobile trips for shopping were still increasing. It is considered to be as a result of increasing the consumption potential by the growth of population and socio-economics in the suburbanized areas in the region.

4. Conclusion

The results of the regression analysis for changes in MRB region between 1975 and 1995, and data simulation indicated that the environmental impacts are increasing by the growth of population and suburbanized activities of commercials with related increase of automobile trips for shopping in the region. The growth of population and urban activities resulted in expansion of suburbanized areas and increasing of environmental emissions of CO_2 and other related environmental impacts.
The expansion of suburbanization areas and activities resulted in increasing CO_2 emissions for about 1.3 times, (about 33% increase) 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 analysis and data simulation for the period of changes between 1975 and 1995 showed the strong correlation of CO_2 emission changes with automobile trips generation to shopping areas, growth of population, and sales annual amount changes.

The results guide to key factors for policy recommendations and strategies for future sustainable development planning, environmental and ecosystem management in the regional scale such as:

1) The need to plan for urban activities and density distribution control of urban areas and services 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 facilities areas, based on the compact cities concept in order to reduce CO_2 emissions caused by automobile shopping trips.
3) The need to reduce the auto access and trips for shopping guide to reduce time distance to shopping areas in order to encourage the soft transport (on foot, and bicycle transport) as the best choice to reduce automobile transport for shopping and related emissions of CO_2.
4) The urgency of the need to reduce CO_2 emission in the urban areas may grant and guide to control the retail areas growth and to direct the development plans and strategies for future growth management, and urban activity control in the regional scale.

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