13. GIS-Based CO₂ Emission Assessment Caused by Suburbanized Activities
Case Study in MUKO River Basin Region for Automobile Trips
GISによる流域圏での郊外化にともなうCO₂発生増加の算定

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Abstract: This paper attempts to estimate CO₂ emission generated by suburbanized urban activities growth. Taking MUKO River Basin Region, Hyogo, Japan as a case study for the emission caused by automobile trips to shopping areas in the region, site significant effects of economic growth and suburban activities growth were found. The analysis was carried out utilizing 1km grid GIS data, 1km statistics data for land use, population allocation, commercial activities, and other related data in this region focusing on the commercial areas where the CO₂ emission by automobile trips is most serious. Comparative analysis for changes assessment between 1975s and 1995s two steps are done as follows; First step is to establish "sales regression model" to explain the correlation of the sales changes with several explanatory variables including population, retail floor space, trip distance and time length from residential area surrounding commercial areas. Second step is to calculate the CO₂ emission amount which is regressed by parameters of the analysis and other statistical data. The results show significant impact of automobile trips generation to shopping areas oriented CO₂ emission on the property value.

Keywords: GIS, CO₂ Emission, Suburbanization, Environmental impacts, Basin Region

1. INTRODUCTION

The rapid urbanization and the high diversified development of urban areas and urban facilities in Japan after the World War II has brought much social efficiency, and has led to occurrence of pollution in areas of large scale urban facilities1. The urbanization and economic growth in MUKO River Basin Region, Hyogo, Japan, starting from 1950s and 1960s, have caused several environmental impacts such as air pollution, water contamination and CO₂ Emissions. The commercial and suburbanized activities are experiencing dramatic growth in the region and resulting in considered environmental changes and related environmental impacts. The population, socio-economic activities data and their changes are analyzed by making effective use of the available data in the region integrating with GIS 1km Grid database and detailed digital maps. The urbanized area expansions of cities surrounding MUKO River Basin, and the current environmental changes affected by the suburbanization activities growth in this region are analyzed and related environmental emissions such as CO₂ are estimated.

2. MUKO RIVER BASIN REGION DATA SET PROCESSING

The population growth in MUKO River Basin Region, a west part of Kansai Metropolitan Region, from 1.5 million in 1975 to 1.7 in 1995* (Fig.1 shows population changes in the region), increasing of infrastructure and railway construction, as well as development of automobile expressways network have resulted in suburbanized urban activities growth which consequently caused a lot of global environmental emissions such as CO₂, local contaminations and other environmental impacts. GIS-based analysis is established to estimate CO₂ emission caused by development of urban facilities in the region based on a comparative analysis between 1975s and 1995s*. The emission of CO₂ brought by expansion of suburbanized urban areas and activities, and automobile access to shopping areas are identified utilizing 1km grid GIS data with their spatial patterns. The analysis was carried out based on considered data of population and commercial activities in the suburbanized areas of Nishinomiya, Takarazuka, Kita-Kobe, Sanda, and Ashia cities of MUKO River Basin Region. Fig.2 shows the boundaries of these cities and classification of their commercial activities patterns.

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2.1 MUKO River Data Boundaries

An integrated GIS data base system for MUKO River Region utilizing 1km grid statistics data was established for time series change analysis. The system was obtained by various categories and types of regional statistical and spatial data such as land use, transportation network, automobile trips time distance, and population allocation. Social activity data and other coverage data for the study area 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. The data have been made for time-series comparative analysis between 1975s and 1995s for studying CO₂ emission changes and related factors. The commercial areas were classified into two major categories, large scale stores and arcades (the traditional shopping areas). These data of commercial allocation were converted also into GIS 1km grid data as shown in Fig. 2.

2.2 Data Sources of CO₂ Assessment in MUKO River Basin Region

The data considered in the analysis included the following:

(A) 1km grid GIS spatial data for population, commercial, land use, etc (1975 to 1995).
(B) Statistical 1km grid data (1975 to 1995).
(C) Japan Statistical Yearbook Data, 2003.
(D) Road Traffic Census Data (1977, 1997).
(E) Other coverage data for the analysis.

3. ESTIMATION PROCESS AND ASSESSMENT OF CO₂ EMISSION

As various data are used for estimation and simulation, GIS-based simulation system is constructed for CO₂ emissions estimation. The system is composed of three modules, a) database establishing, b) models setting and simulation, and c) results displaying for the outputs of the system of data modeling and simulation, Fig.3. Environmental impact elements attributable to management policies are identified and suburbanized areas and activities changes in the region are analyzed in order to direct the future development polices, plans and processes to the environmental management.
3.1 GIS-based Assessment of CO₂ Emission in MUKO River Basin Region

GIS-based analysis of changes in suburbanized urban areas of MUKO River Basin Region was established in 1km grid data for suburbanization and commercial activities to be analyzed. Carbon dioxide emission and its changes for three decades are estimated by designing the calculation model for CO₂ emission depending on the results of the sales regression Model. The impacts of CO₂ emission were divided into three main factors namely; suburbanization increasing impacts, population increasing impacts, and shopping related impacts.

3.2 Analysis Methodology

The analysis process depends on studying the correlation of sales change and automobile trips generation to shopping areas depending on time distance changes and related changes of CO₂ emission rates. The analysis focuses on studying the grid areas, which include the commercial uses and the related CO₂ emission rates and their changes between 1975s and 1995s. The commercial areas were taken as destinations for automobile trips from suburbanized surrounding areas within buffer zone of 10km around shopping grids. These zones were built on the suitable accessibility time from 15-20 min. by automobile for shopping by surrounding residences. The grids of commercial use were selected as the influenced area for estimating CO₂ emission rates caused by residences shopping activities.

4. MODELS OF THE ANALYSIS

4.1 Sales Regression Model

Sales Regression Model was designed to explain the correlation coefficient of the sales changes with several explanatory variables including population, retail floor space, trip distance and time length from residential area surrounding commercial areas, Fig.4 shows sales changes between 1975s and 1995s in MUKO River Basin Region. The Model study the relation between sales changes on commercial areas and related explanatory variables, as shown in Table 1 and Eq. 1, 2, and 3 as inputs of calculation CO₂ emission caused by automobile trips to retail areas. Fig. 4 shows the sales activities changes (increasing / decreasing areas) around MUKO River Region between 1975 and 1995.

The correlation coefficient of sales with population and retails by time distance between the commercial areas and the origins was given for 10km buffering zone around retails centers for each city in the region.

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

where:

- \( S_i \): 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 in commercial areas of 1975 and 1995 were analyzed using the following regressions in Eq.(2), and (3). R & R² of the regression show the strong correlation of the sales with related explanatory variables.
The changes of sales from 1975 to 1995 were given by the following Eq. (4), which give indicator of increasing the sales amount in some areas of analysis related automobile trips for shopping to these areas:

\[
\Delta S_i = S_i(t)_{995} - S_i(t_0)_{975}
\]

where:
- \(S_i\): Sales in the grid (10,000 Yen)
- \(t_0\): census time of 1975
- \(t\): census time of 1995

### Table 2 Estimation results of statistics regression

<table>
<thead>
<tr>
<th>Case</th>
<th>Coefficient estimate 1975</th>
<th>Coefficient estimate 1995</th>
<th>Case</th>
<th>Coefficient estimate 1975</th>
<th>Coefficient estimate 1995</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>252249.26</td>
<td>630877.3</td>
<td>Zone 19</td>
<td>1.0431</td>
<td>-1.0465</td>
</tr>
<tr>
<td>Zone 1</td>
<td>0.2533</td>
<td>-0.3330</td>
<td>Zone 20</td>
<td>1.0945</td>
<td>0.5026</td>
</tr>
<tr>
<td>Zone 2</td>
<td>0.6944</td>
<td>-1.1785</td>
<td>Zone 21</td>
<td>-0.3574</td>
<td>1.9318</td>
</tr>
<tr>
<td>Zone 3</td>
<td>1.6263</td>
<td>-0.0515</td>
<td>Zone 22</td>
<td>-0.7970</td>
<td>1.3430</td>
</tr>
<tr>
<td>Zone 4</td>
<td>-0.1747</td>
<td>-0.9389</td>
<td>Zone 23</td>
<td>-0.3675</td>
<td>1.9787</td>
</tr>
<tr>
<td>Zone 5</td>
<td>0.6181</td>
<td>-0.7438</td>
<td>Zone 24</td>
<td>-0.7807</td>
<td>1.1665</td>
</tr>
<tr>
<td>Zone 6</td>
<td>-0.0409</td>
<td>-0.8145</td>
<td>Zone 25</td>
<td>-0.7267</td>
<td>0.9168</td>
</tr>
<tr>
<td>Zone 7</td>
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<td>-0.4524</td>
<td>Zone 26</td>
<td>-0.8131</td>
<td>-0.9478</td>
</tr>
<tr>
<td>Zone 8</td>
<td>0.3211</td>
<td>-1.1953</td>
<td>Zone 27</td>
<td>2.7361</td>
<td>1.4105</td>
</tr>
<tr>
<td>Zone 9</td>
<td>-0.7885</td>
<td>-0.0156</td>
<td>Zone 28</td>
<td>0.6323</td>
<td>0.7618</td>
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<tr>
<td>Zone 10</td>
<td>0.6406</td>
<td>-2.4153</td>
<td>Zone 29</td>
<td>-0.6149</td>
<td>0.9552</td>
</tr>
<tr>
<td>Zone 11</td>
<td>-0.5295</td>
<td>-0.5770</td>
<td>Zone 30</td>
<td>-0.8182</td>
<td>-1.1753</td>
</tr>
<tr>
<td>Zone 12</td>
<td>-0.6299</td>
<td>-0.1165</td>
<td>Zone 31</td>
<td>1.3611</td>
<td>-0.0192</td>
</tr>
<tr>
<td>Zone 13</td>
<td>-0.5869</td>
<td>0.1469</td>
<td>Zone 32</td>
<td>-0.1718</td>
<td>-0.9279</td>
</tr>
<tr>
<td>Zone 14</td>
<td>-0.0042</td>
<td>1.2328</td>
<td>Zone 33</td>
<td>-0.7347</td>
<td>0.8843</td>
</tr>
<tr>
<td>Zone 15</td>
<td>-0.9229</td>
<td>0.3790</td>
<td>R</td>
<td>0.8793</td>
<td>0.8598</td>
</tr>
<tr>
<td>Zone 16</td>
<td>-0.3869</td>
<td>0.3562</td>
<td>R2</td>
<td>0.7731</td>
<td>0.7393</td>
</tr>
<tr>
<td>Zone 17</td>
<td>1.8212</td>
<td>-0.5937</td>
<td>t</td>
<td>3.7306</td>
<td>5.4932</td>
</tr>
<tr>
<td>Zone 18</td>
<td>-0.2750</td>
<td>-0.7101</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 4.2 CO2 Calculation Model

The CO2 emission in areas of shopping centers, which caused by automobile trips from areas around the commercial area was recognized as one of the most serious urban problems in the region as a result of suburbanization and economic growth. The automobile trips were calculated from surrounding areas to the areas of commercial uses within the considered buffering zones using the model shown by Eq. (5).

\[
Y_{ij} = \left( S_i \times 10^4 \left( \frac{a \times P_j R_i}{d_{ij}^2} \right) \right) \times \left( \frac{1}{E} \right) \times A \times L_{ij} \times U \times \frac{1}{10^6}
\]

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
- \(L_{ij}\): distance length from i to j (km)
- \(E\): living expenditure for one time shopping trip per person (Yen/person)
- \(A\): automobile rate from all transportation
- \(U\): CO2 exhaust unit (g-CO2/person "km"
Changes of CO₂ emissions for time series between 1975s and 1995s were estimated using the Eq. (6):

\[ Y_{ji} \text{ changes} = Y_{ji} (t) - Y_{ji} (t_0) \]

\[ Y_{ji} (t - t_0) = Y_{ji} (1995) - Y_{ji} (1975) \]

where:

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

5. RESULTS AND DISCUSSION

The regression model for sales changes analysis and CO₂ calculation Model estimated the CO₂ emission rates caused by automobile trips to shopping areas for 1975, and 1995. The results of analysis are displayed on GIS as shown in Figs. 5 and 6. Taking the rate of car using density from all traffic 28.7% for 1975, and 38.4% for 1995⁸ (Road traffic census (1977, 1997). The car average speed on road accessibility to shopping areas in grid (i) from surrounding residential areas in grid (j), which used for time distance calculation (d_{ij}) from grid j to i, were divided into two major zones in this region as shown in Table (3).

![Fig. 5 CO₂ emission rates around shopping areas in 1979](image)

![Fig. 6 CO₂ emission rates around shopping areas in 1995](image)

The results of the comparative analysis for changes of CO₂ emission rates gives the indicators of increasing values of CO₂ emissions caused by the automobile trips to shopping areas for changes from 1975 to 1995 as shown in Figs. 5, 6 and 7, which indicated that the emission rates in commercial grids of level ranged from 100-200 t-CO₂ was increased from 6 to 8 grids and for emission level ranged from 200-300 t-CO₂ was increased from 3 to 6 grids and for level more than 300 t-CO₂ was increased from 2 to 3 grids, as given in Table 4. The simulation results indicate that the rates of CO₂ emission in the region are increased.

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

<table>
<thead>
<tr>
<th>Area zone</th>
<th>1977</th>
<th>1997</th>
</tr>
</thead>
<tbody>
<tr>
<td>South-Hanshin area</td>
<td><strong>NISHINOMIYA, TAKARAZUKA</strong></td>
<td>29.3</td>
</tr>
<tr>
<td>North-Hanshin Area (SANDA, KOBE-KITA,NORTH : NISHINOMIYA)</td>
<td>40.6</td>
<td>44.1</td>
</tr>
</tbody>
</table>

*Road traffic census (1977, 1997)⁸

### Table 4 Changes of CO₂ emission around commercial areas in MUKO River Basin from 1975s to 1995s

<table>
<thead>
<tr>
<th>CO₂ emission level (t/km²)</th>
<th>Emission in 1979/1km grid</th>
<th>Emission in 1995/1km grid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of grids</td>
<td>%</td>
</tr>
<tr>
<td>1-100</td>
<td>20</td>
<td>58.82</td>
</tr>
<tr>
<td>100-200</td>
<td>6</td>
<td>17.65</td>
</tr>
<tr>
<td>200-300</td>
<td>3</td>
<td>8.82</td>
</tr>
<tr>
<td>300-&lt;</td>
<td>2</td>
<td>5.88</td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>100</td>
</tr>
</tbody>
</table>

![CO₂ Changes on Commercial areas/1km Grid in MUKO River Basin Region between 1975s and 1995s](image)

![Fig. 11 CO₂ emission rates changes around shopping areas for time series between 1975s and 1995](image)
The results of calculation Model and changes estimation give indicators that the places where the increase in CO₂ emissions is remarkable increasing in population and sales in the suburban area of Kita-Kobe City and Sanda City, also the southern Nishinomiya and southern Takarazuka. These results led to find out that CO₂ emissions are increasing in the whole commercial areas of MUKO River Basin Region.

Although sales in this commercial areas of MUKO River Basin Region are decreasing for the time series between 1975s and 1995s, the emission of CO₂ caused by automobile trips to shopping areas is still increasing, it is considered to be because of the increasing of consumption potential by the increasing of population in the suburbanization areas surrounding commercial areas in the Region.

6. CONCLUSION

The results of the changes time series comparative analysis between 1975s, 1995s and data simulation guide to know how much is the relation of CO₂ emission rates changes with automobile trips generation to shopping areas, population growth, and sales change. The results of the regression and data simulation guide to key factors for policy recommendations for future sustainable development planning, environmental and ecosystem management in the regional scale.

The simulation showed that the change of sales amount of retail areas results in change of CO₂ emission generated by car trips increasing for shopping activities. The retail area density distribution and the centralization of commercial areas and related increasing of CO₂ emission rates generated by automobile trips from the expansion of suburbanized urban areas in the region guides to plan for reducing the time distance from the residential areas to this commercial areas in order to reduce the generated emissions.

The urgency of the need to reduce CO₂ emission in urban areas may grant and guide to control the direction of the retail areas growth and urban areas growth in order to direct the development plans and strategies for growth management, urban control, and CO₂ reduction.

REFERENCES


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