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1. Introduction

The current state of land use is the result of a variety of factors, caused by both biophysical and socio-economic conditions, and their interactions. Land-use features prominently in many disciplines such as geography, economics, civil engineering, architecture, city and rural planning, soil science, forest management, and so on. But the study of land-use is often limited to only one discipline. There are only a few studies where the influence of both natural and socio-economic factors on land-use is simultaneously investigated. The purpose of this study is to demonstrate the relations among land use, socio-economic variables and geophysical factors in the case study area of Kansai district, Japan. This region contains the second largest urbanized area in Japan (after the Tokyo metropolitan area), while maintaining significant paddy rice cultivation in the suburban surroundings. Here we seek to extract the crucial relationships between land use in the Kansai district and the associated factors with statistical techniques.

In general, land-use change can be separated into two levels. "Minor land-use change" is land-use change within the same economic sector. "Major land-use change" means land-use conversion from one major industry to another [Black, 1931; Wada, 1980]. For example, according to this classification, a crop change in agriculture is a minor land-use change, and land-use conversion from farmland to residential land is a major land-use change.

In this study, we focus mainly on major land-use change. A first reason is that land-use conversion usually brings about permanent change. Conversion to residential land from any other land-use, and even conversion from farmland to forest land are actually irreversible processes[1]. The second reason is a practical one, since it is difficult to obtain the detailed land-use data that are prerequisites for within category land-use analysis.

In this paper, we first present some basic information on the case study area, describe the characteristics of the local agriculture and briefly discuss the statistical data used in the case study. The subsequent analysis consists of two parts: an analysis of the distribution of land uses and an analysis of the driving forces of land-use change.

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[1] Once farmland, especially that used for paddy rice is transferred to forest land, it is quite expensive to return the land to paddy field with the requisite flat land surface and irrigation facilities. From an economics point of view, it is impossible.

The distribution of land use is represented by percentage of total area. We calculate the static relationships between the distribution of land uses and socio-economic and geophysical factors. We then try to elucidate whether the static relations are temporally stable, i.e. how these relationships have changed during the study period from 1970 to 1990.

For farmland and residential land we investigate what kind of socio-economic factors as well as natural conditions explain the temporal changes of these major land-use categories during the study period. Through these analyses, we extract some driving forces of land-use change in the study area.

The data set for this study was originally developed in the project "Land-use and Global Environment Change" (LU/GEC, 1995) sponsored by the National Institute for Environmental Studies, Japan.

2. Case study area

We selected the Kansai district of Osaka, Kyoto and Shiga prefectures as the study area (Table 1, Figure 1). Hyogo prefecture is also a part of the Kansai district, but because of damage caused by the recent Great Kansai Earthquake in 1995, we exclude this area from the analysis. The total extent of the study area is about 9,845km^2; the total population in 1990 was 12.6 million. From 1970 to 1990, the population increased by 16.7 percent.

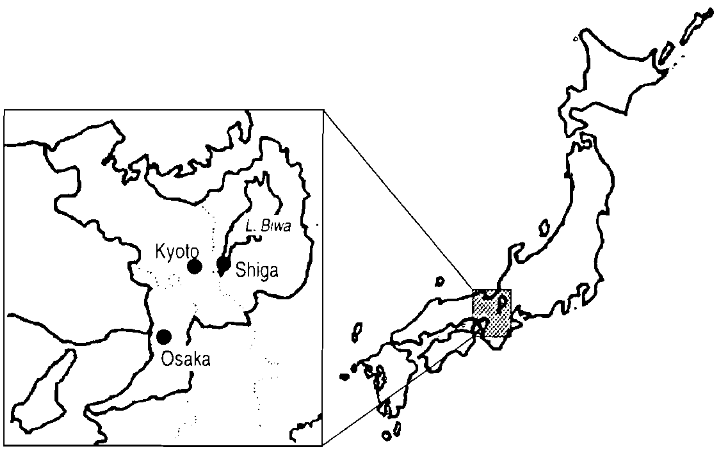

Fig. 1. Kansai district, Japan.

Table 1. An Abstract of the Study Area.

Case study area	3 prefectures (Shiga / Kyoto / Osaka)
Total area	9845.2 km^2
Population in 1970	10,760,335
Population in 1990	12,559,389
Number of samples	All 138 municipalities
Years of data	1970 , 1980* and 1990**

* In this analysis, data for 1980 are not used.

** Land-use data for Kyoto prefecture are not available for 1990.

Suburban farm households

Paddy-rice farming is the most typical agricultural land use farming in the study region, as in other suburban areas in Japan. Suburban farm households, engaged in paddy-rice farming are characterized by:

- **Dependence on paddy-rice farming.** Recent price stagnation of agricultural products, mainly caused by trade liberalization and retrenchment of price-support policy, as well as outflow of agricultural labor force to non-agricultural sectors prevents farm households in urban fringes to cultivate crops other than rice, despite the high biophysical potential for other crops.
- **Dependence on non-agricultural jobs.** Because of the development and diffusion of agricultural machinery since the early 1970's, rice cultivation is no longer a labor-intensive activity. Suburban farm households have reduced farm labor by mechanization and application of agro-chemicals (fertilizer, pesticides, herbicides, etc.), and now engage their labor in more profitable sectors. As a result, suburban farm households earn the larger part of their income from non-agricultural work, and the average income of farm households exceeds that of wage-earner households.
- **High depreciation expense.** Although the most suitable farm size for mechanized paddy-rice farming is more than 10 hectares, the average farm size of the case study region is only approximately one hectare. Joint ownership or common use of agricultural machinery has not spread among the farm households. Therefore a purchase of machinery is a large investment for most farm households, and depreciation expenses greatly reduce the profits of paddy-rice farming.
- **Strong intention of farmland holding.** Suburban farm households find that it is relatively profitable to hold land as farmland because of the expectation of increases in land prices. Farmland also enjoys preferential treatment in fixed property and inheritance taxes. Farm households without entrepreneurial ambitions and abilities do not aggressively convert their own farmland to other land uses. Most farmland conversions are caused by sales of farmland to developers and public authorities. In general, however, farm households do not sell their land so long as there are not special reasons such as house reconstruction or marriage of children. Besides, the farm households are apt to stick to production of rice for their own home consumption. When farmland size decreases to near a minimum level for self-sustenance (around 30 are), they refrain from disposal of farmland.

The behavior of farm households in suburban areas is not expected to change in the coming decade. While engaging in another jobs besides farming, the households will hold their farmland and continue to grow rice.

3. Data and Indicators

The municipality is chosen as the unit of analysis rather than other units based on homogeneity of socio-economic or natural conditions, because of data availability. Figure 2 shows data availability for the study area. Hatched ovals in the figure indicate that data are included in the digital database. Most socio-economic statistics are available at five-year intervals at the municipality level. Land-use data and geophysical data are also available, although the number of times when surveys were carried out is very limited.

Socio-economic data

The dataset for the year 1990 contains more variables than that for 1970. For comparability, we do not make use of variables for 1990 when they are not available for 1970. The 1970 economic statistics are adjusted to 1990 values by a price index.

The socio-economic variables and their sources are:

- Population data (Population Census, 1970, 1980, 1990),
- Farm household and agricultural labor data (Agricultural Census, 1970, 1980, 1990),
- Employment data(Population Census / Business Statistics, 1970, 1980, 1990),
- Distance to Osaka /Kyoto center (manual survey data).

Land use factors such as planning regulations and land prices are not treated here.

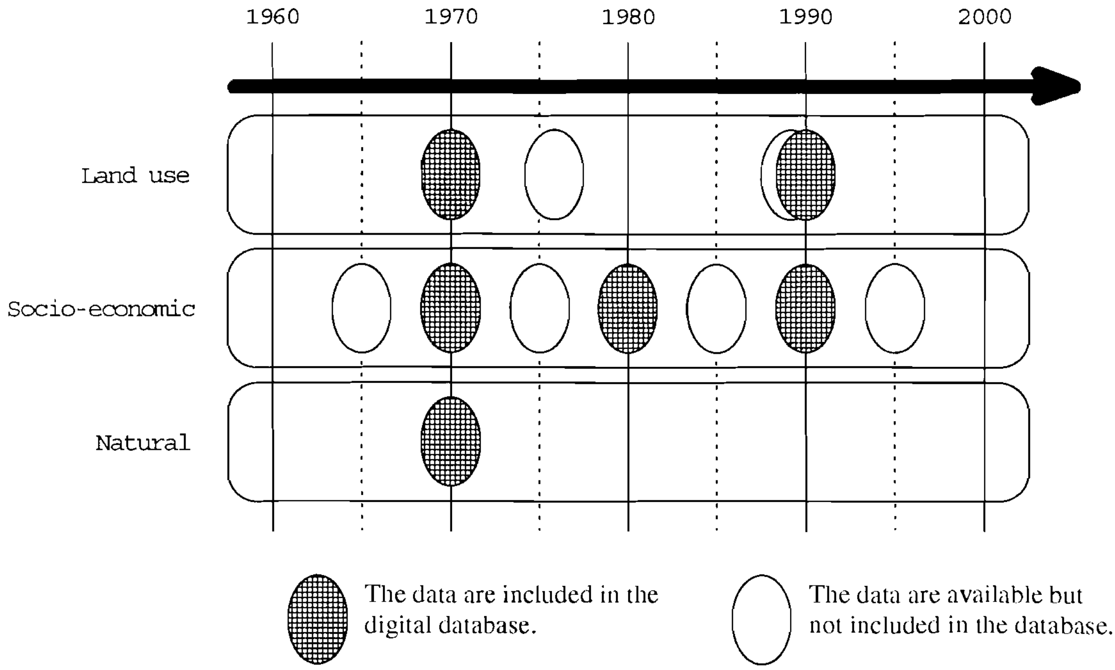

Fig. 2. Data availability for the study area.

Geophysical data

The source of the geophysical data is the "*Land Classification Map*", and its attached material, published in 1970 by the National Land Agency of Japan. Variables included are elevation, slope, topography, geological features and soil features at the municipality level. Since the agricultural land-use pattern in the suburban zone has not greatly changed during the study period (described in previous section), geological and soil variables that are closely related to agricultural production capability are not used in the analysis. Some detailed topographic categories are aggregated into broader classes to make them suitable for analysis.

Land-use data

Land-use data for 1970 and 1990 were tabulated, but from different data sources. The source of the 1970 data is the same as the geophysical data. The 1990 data were provided by the prefectural governments. Land-use data of Kyoto for 1990 were not available by circumstances of the prefecture. As directed by the National Land-use Planning Act (1974), prefectural governments have to investigate land-use conditions in their jurisdiction regularly. Since the land-use categories of the historical data sets are different to some extent, the categories of both surveys were integrated into a common set of four classes. Table 2 shows the four major land-use categories used in the study and the corresponding original categories of the two data sets of 1970 and 1990, respectively.

Table 2. Unification of Land-use Categories.

Categories in this study	Categories in Land Classification Map(1970)	Categories in "National Land-use Planning Act" (1990)
Farmland	**Farmland** • Paddy field • Upland field • Land under perennial crops	**Land for agricultural use**
Forest land	**Forest land** • Artificially-reproduced forest • Natural forest/coniferous tree • Natural forest/broad-leafed tree • The total sum of natural forest • Wilderness (grassland, grassy, place, bamboo thicket, land exempt from tax, others)	**Forest land** **Wilderness**
Residential land	**Residential land**	**Land for urban use** • Residential area • Industrial land-use • Other residential land
Land for public use / and others	**Land for public use / and others**	**Water surface / river / waterway / roads / and others**

Indicators

Indicators or variables are the basic elements of the analysis. Since the municipalities are widely different in absolute scale, most indicators are either standardized by dividing by total area, total number of household, total population etc., or expressed as proportions. Given the limitation of data availability, indicators expected to relate to land use were carefully selected.

The list of indicators included in the analysis is shown in Table 3. The indicators are divided into five categories: (A) natural conditions, mainly geophysical characteristics, (B) socio-economic conditions including population and household structure, employee structure, economic activities, and urban accessibility, (C) temporal changes of the socio-economic indicators during the study period, (D) land-use indicators of the four major categories and (E) their temporal changes. Many indicators were excluded from the analysis due to the unavailability of 1970 data.

Table 3. List of Indicators and Variable Names.

Indicator	Variable name (in 1970)	(common*)	(in 1990)
Section A : Natural conditions			
Percentage of 0-3 degree slope area		SLOPE1	
Percentage of 3-8 degree slope area		SLOPE2	
Percentage of 8-15 degree slope area		SLOPE3	
Percentage of 15 degree and over slope area		SLOPE4	
Percentage of 0-100m elevation area		ELEV1	
Percentage of 100-200 m elevation area		ELEV2	
Percentage of 200 m and over elevation area		ELEV3	
Percentage of mountain and volcano area		MOUNTAIN	
Percentage of hill area		HILLS	
Percentage of plateau & tableland area		PLATEAU	
Percentage of lowland area		LOWLAND	
Section B : Socio-economic conditions			
Total population	TPOP70		TPOP90
Population density	POPDEN70		POPDEN90
Percentage of population less than & equal to 14 years old	POP70_14		POP90_14
Percentage of population from 15 to 64 years old	POP70_64		POP90_64
Percentage of population more than & equal to 65 years old	POP70_65		POP90_65
Farm-household ratio (= farm households / total households)	FARMP70		FARMP70
Percentage of full-time farm household	FULL_F70		FULL_F90
Percentage of part-time farm household (type 2)	PART_F70		PART_F90
Percentage of employees in secondary industry	SECOND70		SECOND90
Percentage of employees in tertiary industry	TERTIA70		TERTIA90
Ratio of female agricultural laborers to total agricultural laborers	AG_WK70		AG_WK90
Percentage of employees in the construction industry	CONST70		CONST90
Percentage of employees in the manufacturing industry	MANU70		MANU90
Percentage of employees in the public utilities (electricity, water, gas, etc.)	PUBLIC70		PUBLIC90
Percentage of employees in the transportation & communication industries	TRANS70		TRANS90
Percentage of employees in the whole sale, retail sale and food dispensing business	SALE70		SALE90
Percentage of employees in the financial and insurance business	FINA70		FINA90
Percentage of employees in the service industry	SERV70		SERV90
Gross field husbandry product per unit farmland	FLD70_FL		FLD90_FL
Gross horticultural product per unit farmland	HOR70_FL		HOR90_FL
Gross animal husbandry product per unit farmland	ANI70_FL		ANI90_FL
Gross farm product per unit farmland (=c1+c2+c3)	AGR70_FL		AGR90_FL
Average farm size	FSIZE70		FSIZE90
Per capita gross farm product	AGR70_P		AGR90_P
Per capita farmland	FLND70_P		FLND90_P
Number of agricultural laborers per unit farmland	AGW70_FL		AGW90_FL
Number of non-agricultural jobs per 100 people	NJOB70_P		NJOB90_P
Number of employees per one business firm	EMP70_FM		EMP90_FM
Distance to city center of osaka / kyoto		DISTANCE	

*Common variables are used for both 1970 and 1990.

Section C : Temporal changes during the study period

Change in total population	S_TPOP
Change in population density	S_POPDEN
Change in percentage of population less than & equal to 14 years old	S_POP_14
Change in percentage of population from 15 to 64 years old	S_POP_64
Change in percentage of population more than & equal to 65 years old	S_POP_65
Change in farm-household ratio	S_FARMP
Change in percentage of full-time farm household	S_FULL_F
Change in percentage of part-time farm household (type 2)	S_PART_F
Change in percentage of employees in secondary industry	S_SECOND
Change in percentage of employees in tertiary industry	S_TERTIA
Change in ratio of female agricultural laborers to total agr. laborers	S_AG_WK
Change in percentage of employees in the construction industry	S_CONST
Change in percentage of employees in the manufacturing industry	S_MANU
Change in percentage of employees in the public utilities (electricity, water, gas, etc.)	S_PUBLIC
Change in percentage of employees in the trans. & comm. industries	S_TRANS
Change in percentage of employees in the whole sale, retail sale and food dispensing business	S_SALE
Change in percentage of employees in the financial and insurance business	S_FINA
Change in percentage of employees in the service industry	S_SERV
Change in gross field husbandry product per unit farmland	S_FLD_FL
Change in gross horticultural product per unit farmland	S_HOR_FL
Change in gross animal husbandry product per unit farmland	S_ANI_FL
Change in gross farm product per unit farmland (=c1+c2+c3)	S_AGR_FL
Change in average farm size	S_FSIZE
Change in per capita gross farm product	S_AGR_P
Change in per capita farmland	S_FLND_P
Change in number of agricultural laborers per unit farmland	S_AGW_FL
Change in number of non-agricultural jobs per 100 people	S_NJOB_P
Change in number of employees per one business firm	S_EMP_FM

Section D : Land-use indicators

Percentage of farmland	FARM70	FARM90
Percentage of forestry land	FOREST70	FOREST90
Percentage of residential land	URBAN70	URBAN90
Percentage of land for public use and others	OTHERS70	OTHERS90

Section E : Land-use change during the study period

Change in percentage of farmland	S_FARM
Change in percentage of forestry land	S_FOREST
Change in percentage of residential land	S_URBAN
Change in percentage of land for public use and others	S_OTHERS

4. Land-use structure and its temporal stability

4.1 Methods of Analysis

Figure 3 shows the framework of the analysis. We apply Canonical Correlation Analysis (CCA) to estimate the relationships between land use and its driving forces. CCA is a multivariate statistical technique that investigates the relationship between two sets of variables simultaneously. One is the predictor set, that is, the set of independent variables, and the other is the set of criterion measures. This statistical method is particularly appropriate when the criterion variables themselves are correlated with each other. In such cases, CCA can uncover complex relationships that reflect the structure between the predictor and criterion variables [Okuno et. al., 1982, Dillan & Goldstein, 1984]. Pioneering work by Matsuo applied canonical correlation analysis to the estimation of land-cover mixing ratios using MSS data and geophysical data [Matsuo 1985, Matsuo et al. 1985].

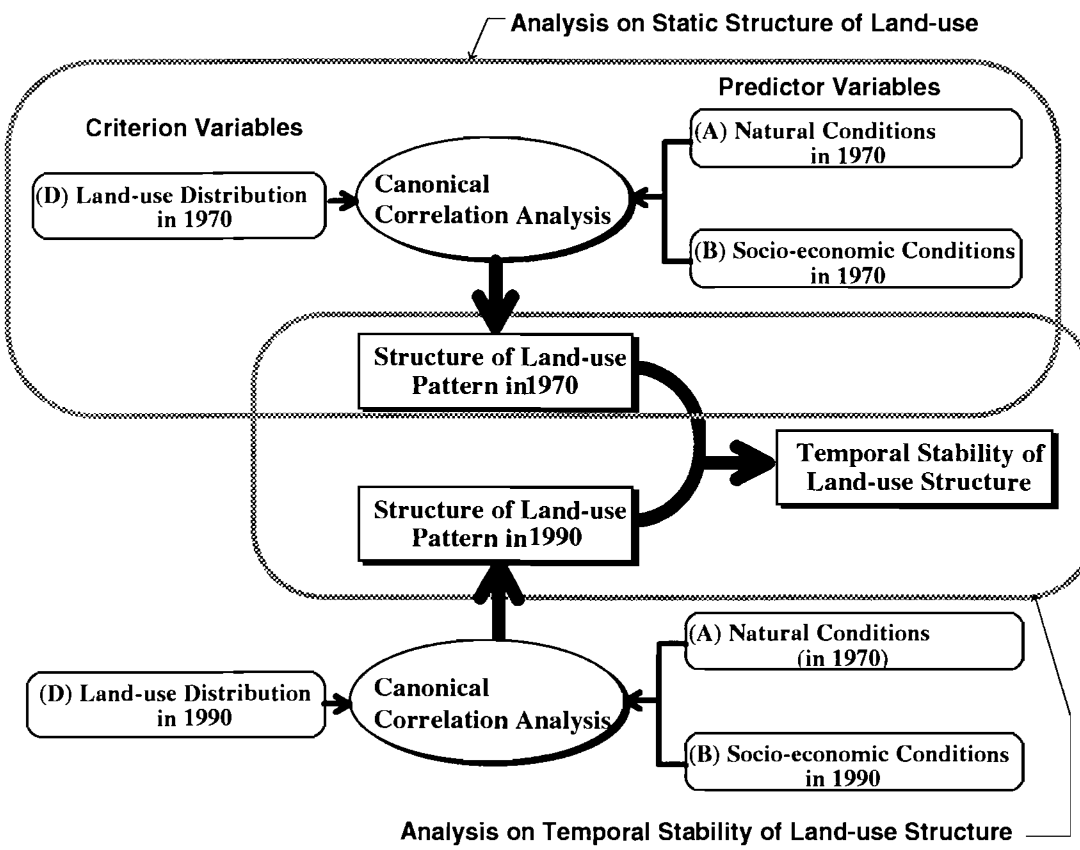

Fig.3. Framework of Analysis for Land-use Distribution.

Table 4. Land-use structure : Results from canonical correlation analysis (1970).

Variable name	*Indicator*	*Canonical loadings in 1970* 1st var.	2nd var.	3rd var.
	Land-use indicators			
FARM	% of farmland	0.43	0.90	-0.06
FOREST	% of forestry land	-0.97	-0.23	-0.09
URBAN	% of residential land	0.85	-0.49	-0.18
OTHERS*	% for public & others	0.66	0.10	0.75
	canonical correlation coefficient	**0.99**	**0.96**	**0.72**
	percent of variance	**98%**	**93%**	**52%**
	Socio-economic conditions			
TPOP	total population	0.29	-0.33	-0.09
POPDEN	population density	0.75	-0.52	-0.22
POP_14	% of pop under 15	0.35	-0.34	-0.01
POP_65	% of pop over 65	-0.73	0.34	-0.08
FARMP	farm-household ratio	-0.59	0.50	-0.14
FULL_F	% of full-time farm hh	0.07	0.01	0.24
PART_F	% of part-time farm hh (type 2)	0.14	-0.60	-0.13
SECOND	% of employee in secondary	0.49	-0.39	0.00
TERTIA	% of employee in tertiary	0.45	-0.40	0.17
AG_WK	ratio of female agr. laborers	-0.13	0.10	-0.13
CONST	% in the construction industry	-0.43	0.15	0.03
MANU	% in the manufacturing industry	0.31	-0.02	0.05
TRANS	% in the trans. & comm. industry	-0.03	-0.09	-0.08
SALE	% in the whole sale, retail sale	0.04	0.03	0.00
FINA	% in the financial and insurance	0.13	-0.19	0.02
SERV	% in the service industry	-0.36	-0.02	-0.07
FLD_FL	field husbandry product/farmland	0.30	0.11	-0.02
HOR_FL	horticultural product / farmland	0.29	-0.21	-0.05
ANI_FL	animal product / farmland	0.40	-0.42	0.00
AGR_FL	farm product / farmland	0.49	-0.38	-0.03
FSIZE	average farm size	-0.36	0.76	-0.07
AGR_P	per capita gross farm product	-0.39	0.58	-0.03
FLND_P	per capita farmland	-0.47	0.59	-0.16
AGW_FL	# of agr. laborers / farmland	0.51	-0.65	0.13
NJOB_P	# of non-agricultural jobs /pop	0.12	-0.09	-0.10
EMP_FM	# of employee / business firm	0.56	-0.26	0.08
DISTANCE	distance to city center	-0.52	0.24	-0.10
	Natural conditions			
SLOPE1	% of 0-3 degree slope area	0.94	0.28	-0.10
SLOPE2	% of 3-8 degree slope area	-0.20	-0.14	0.68
SLOPE3	% of 8-15 degree slope area	-0.55	-0.18	0.12
SLOPE4*	% of 15 degree & over slope area	-0.80	-0.19	-0.27
ELEV1	% of 0-100m elevation area	0.85	-0.08	0.12
ELEV2	% of 100-200 m elevation area	-0.19	0.49	0.12
ELEV3*	% of 200 m & over elevation area	-0.83	-0.26	-0.22
MOUNTAIN	% of mountain and volcano area	-0.87	-0.32	-0.22
HILLS	% of hill area	0.01	-0.01	0.60
PLATEAU	% of plateau & tableland area	0.40	-0.06	0.00
LOWLAND	% of low land area	0.70	0.38	-0.09

* Excluded from canonical correlation analysis but canonical loadings are calculated.

In this study, the predictor set is the natural and socio-economic conditions and the criterion set is the percentages of the four major land-use categories[2]. Close relationships among different kinds of land use are normally expected, so in this case the application of CCA is very appropriate. Temporal stability of the land-use structure is also elucidated by comparing the two results for the 1970 and 1990 data.

4.2 Results of canonical correlation analysis of 1970 data

The values of the canonical loadings[3] obtained for the 1970 data are shown in Table 4. Values of canonical correlation for 1970 were 0.99, 0.96, 0.73 respectively, in ranking order of the variates. Table 5 shows a summary of the three variates for 1970. Indicators marked with "❑ " are land-use variables, those with "◊" are natural indicators, and those with "♦" are socio-economic. In the following, we discuss the statistical relationships between the two sets of variables shown in Table 5.

Table 5. Summary of canonical correlation variate (Data set: 1970).

		- - <-0.7	- -0.5 - -0.7	0	+ 0.5 - 0.7	++ > 0.7
1st variate	y	❑forestry land			❑farmland** ❑land for public use & others	❑residential land
	x	◊ % of mountain / volcano ◊ % of >200m elevation area ◊ % of >15 degree slope are ♦ % of population over 65	♦ farm-household ratio ◊ % of 8-15 degree slope ♦ distance to Kyoto, Osaka ♦ per capita gross farm products		♦ # of employees per farmland ♦ # of agr. laborers per farmland ♦ gross farm product per farmland*	◊ % of 0-3 degree slope area ◊ % of 0-100m elevation area ♦ population density ◊ % of lowland area
2nd variate	y		❑residential land*			❑farmland
	x		♦ # of agr. laborers per farmland ♦ % of part-time farm hh. (type 2) ♦ population density		♦ per capita farmland area ♦ per capita gross farm product ♦ farm-household ratio ◊ % of 100-200m elevation area	♦ average farm size
3rd variate	y					❑land for public use & others
	x				◊ % of 3-8 degree slope area ◊ % of hill area	

Remarks: ❑ : Land-use variables, ◊ : Geophysical indicators, ♦ : Socio-economic indicators. Indicators with underline are related to agriculture. * : Value of the canonical loading is 0.49. ** : Value of the canonical loading is 0.43.

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2 Multicollinearity is the undesirable situation where one of the independent variables is a linear function of other variables (linearly dependent). Estimates of regression coefficients become unstable as the degree of multicollinearlity increases. The same problem may happen in canonical correlation analysis. Because the four land-use indicators are linearly dependent, one of them (OTHERS) is excluded from canonical correlation analysis. The correlation coefficients between the canonical variates of the criterion set and OTHERS (the excluded land-use indicator) are calculated as the canonical loadings for OTHERS (See footnote 3). In the same way, some indicators (SLOPE4 and ELEV3) in the predictor set are also excluded from the analysis and the canonical loadings are estimated from the correlation coefficients. In addition, by a variable-removal test, we ascertain that there is no multicollinearity problem in this analysis.

3 Correlation coefficients between canonical variate and corresponding original indicators.

The first coordinate

- **Criterion set:** The canonical loading for forestry land is -0.97 and loadings for residential land, land for public use, and farmland are 0.85, 0.66 and 0.43 respectively. Thus the first coordinate represents the differentiation between "less-managed[4]" forest land and the other more highly managed land uses.
- **Predictor set:** Geophysical indicators such as slope, elevation and topography dominate the first canonical variate of the predictor set although many socio-economic indicators also show moderate correlation values. Canonical loadings for percentage of 0-3 degree slope area, percentage of 0-100m elevation, and percentage of lowland area are positive and large. On the other hand, those for percentage of mountain area, percentage of >200m area, percentage of >15 degree slope area, and percentage of 8-15 degree slope area were negative and large. These geophysical indicators clearly show that the share of forestry land tends to be high in places where the percentage of mountain area is high, elevation is above 200m, and slopes are steep. On the other hand, shares of the other three types of land use tend to be relatively high in places where the percentage of lowland is high, elevation is low, and slopes are gentle.

  For the socio-economic indicators, canonical loadings for population density, number of employees per business firm, number of agricultural laborers per farm, gross farm product per farm, and percentage of employees in secondary industry, were positive and relatively large. Those for percentage of population over 65 years old, farm-household ratio[5], distance to the urban center, and per capita gross farm product were negative. These socio-economic indicators of the first coordinate show the differences in economic activities and demographic features between urban areas and rural areas. The intensive use of farmland was positively related to the share of residential land, but per capita farm product was negatively related.

  The first coordinate on the predictor side is a combination of the strong geophysical factors that represent major topographical differences and the moderate socio-economic factors that represent urbanization in the broad sense.

The second coordinate

- **Criterion set:** The canonical loading for farmland is 0.90, and for residential land -0.49. Therefore, the second coordinate represents the differences between residential and farmland.
- **Predictor set:** From Table 5, we ascertain that socio-economic factors rather than geophysical conditions contribute to differences between residential and farmland. Seven socio-economic

4 Industrial forest land now occupies only a small part of the district. While the percentage of planted forest in the district is high (39 % in 1990), most forest industry has been abandoned, leaving much of the forest land in the district in an unmanaged state.

5 The farm-household ratio is an indicator of "rurbanization", representing the level of urbanization in rural community. It also shows the level of mixed rural-urban landscape. Because the behavioral patterns and cultural values of farm households and non-farm households differ, "rurbanization " affects not only social relations in the community, but also farming practices and living environments.

indicators are found in the predictor set of the second coordinate. Canonical loadings for average farm size, per capita farmland area, per capita gross farm product, and farm-household ratio are positive. On the other hand, canonical loadings for the number of agricultural laborers per farmland, percentage of part-time farm households (type 2)[6], and population density are negative. Percentage of 100-200m elevation area is the only geophysical indicator and its canonical loading is positive. All socio-economic indicators except population density are closely related to agriculture and farm management. Both the average farm size and the percentage of part-time households represent the agricultural income level of the farm households. The per capita farmland and per capita gross farm product represent the industrial scale of the agricultural sector, while the farm-household ratio represents the share of households that engage in farming. From these points, we determine that the second coordinate describes the level of economic activity based on agriculture at the farm and local levels.

<u>The third coordinate</u>

- **Criterion set:** Land for public use and other users is the only land-use indicator that shows a high value (0.75) of canonical loading for the third coordinate. So, this coordinate characterizes the special conditions of land used for public and other purposes.
- **Predictor set:** Dominant explanatory factors do not exist but some geophysical indicators such as percentage of 3-8 degree slope area and percentage of hill area have relatively high values of canonical loadings. It may be argued that for public uses such as roads, highways, and large-scale public utilities, the local governments and the authorities concerned might be apt to choose hillside sites because of low land prices. This is consistent with our empirical knowledge of land-use dynamics in general.

Structure of the land-use distribution

By applying the canonical correlation analysis, some well-structured relationships between land use and a set of geophysical and socio-economic factors could be extracted.

Figure 4 summarizes the structure of the land-use distribution in 1970. The first canonical variate separated forestry land from the other major land uses. This was mainly explained by the topographical differences between mountain areas and lowland areas. The socio-economic differences between urban areas and rural areas also were operative in the distinction of the forest land-use pattern from the other three types. The second canonical variate distinguished farmland from residential land. This was explained by the level of economic activity based on agriculture at the farm and local levels. The third variate distinguishes the land for public and other uses, explained by some geophysical conditions.

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[6] The part-time farm household (type 2) is a farm household that earns its main income from non-agricultural jobs.

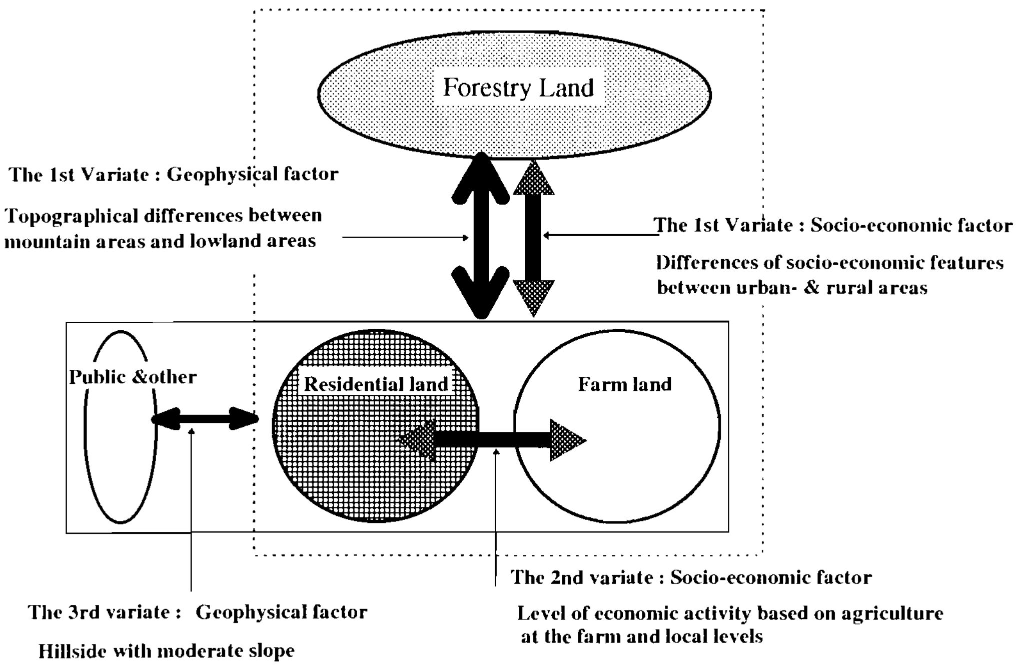


Fig. 4. Structure of land-use distribution extracted by canonical correlation analysis.

4.3 Temporal Change of the Land-use Structure

In the previous analysis the data of 1970 were used. Now we apply canonical correlation analysis to the 1990 data. Results are shown in Table 6. By comparing both sets of the canonical loadings obtained for different time points, we determine how the structure of land use has changed during these 20 years. The geophysical indicators of 1970 were also used for 1990.

Figures 5, 6 and 7 compare the different sets of canonical loadings of 1970 and 1990. From Figure 5, which shows the canonical loadings of the first variate, we conclude that both the land-use indicators of criterion variables and the factors of predictor variables have hardly changed during the study period. Figure 6 shows the comparison of the second canonical variate. The two sets of land-use indicators coincide well. Some population and household indicators such as population density (POPDEN), farm-household ratio (FARMP), and some indicators related to agriculture (FSIZE, AGR_P, FLND_P, AGW_FL) have hardly changed, although most indicators related to employee structure have changed considerably. Canonical loadings for the indicators related to the secondary industry such as SECOND, CONST and MANU increased positively. On the other hand, canonical loadings for the indicators related to tertiary industry such as TERTIA, TRANS, SALE, FINA and SERV become more negative. As a result, the relationship between residential land use and tertiary industry has strengthened during the period. Comparing the third variate of 1970 and 1990 (Figure 7), we conclude that the canonical loading of land-use variables and explanatory geophysical indicators have not changed much.

Thus we can determine that the land-use structure of the study area has had considerable temporal stability. In particular, temporal changes in the contributions of geophysical factors were small in each canonical variate.

Table 6. Land-use structure : Results from canonical correlation analysis (1990).

Variable name	*Indicator*	*Canonical loadings in 1990* 1st var.	2nd var.	3rd var.
	Land-use indicators			
FARM	% of farmland	0.27	0.96	-0.07
FOREST	% of forestry land	-0.98	-0.17	-0.05
URBAN	% of residential land	0.86	-0.49	-0.17
OTHERS*	% for public & others	0.82	-0.22	0.53
	canonical correlation coefficient	**0.99**	**0.98**	**0.83**
	percent of variance	**99%**	**95%**	**69%**
	Socio-economic conditions			
TPOP	total population	0.33	-0.35	-0.01
POPDEN	population density	0.72	-0.60	-0.15
POP_14	% of pop under 15	-0.25	0.47	0.09
POP_65	% of pop over 65	-0.59	0.38	-0.35
FARMP	farm-household ratio	-0.56	0.51	-0.27
FULL_F	% of full-time farm hh	0.00	-0.21	0.39
PART_F	% of part-time farm hh (type 2)	0.03	0.10	-0.46
SECOND	% of employee in secondary	-0.07	0.47	-0.24
TERTIA	% of employee in tertiary	0.31	-0.60	0.30
AG_WK	ratio of female agr. laborers	-0.01	0.12	-0.30
CONST	% in the construction industry	-0.31	0.38	-0.24
MANU	% in the manufacturing industry	0.03	0.40	-0.07
TRANS	% in the trans. & comm. industry	0.23	-0.31	-0.19
SALE	% in the whole sale, retail sale	0.36	-0.40	0.15
FINA	% in the financial and insurance	0.31	-0.40	0.13
SERV	% in the service industry	-0.19	-0.28	0.25
FLD_FL	field husbandry product/farmland	0.02	0.58	-0.27
HOR_FL	horticultural product / farmland	0.40	-0.44	0.36
ANI_FL	animal product / farmland	0.08	-0.14	0.20
AGR_FL	farm product / farmland	0.41	-0.36	0.38
FSIZE	average farm size	-0.38	0.78	-0.09
AGR_P	per capita gross farm product	-0.43	0.61	-0.14
FLND_P	per capita farmland	-0.47	0.60	-0.22
AGW_FL	# of agr. laborers / farmland	0.52	-0.68	0.11
NJOB_P	# of non-agricultural jobs /pop	0.31	-0.06	-0.22
EMP_FM	# of employee / business firm	0.34	-0.12	0.21
DISTANCE	distance to city center	-0.54	0.51	-0.26
	Natural conditions			
SLOPE1	% of 0-3 degree slope area	0.94	0.25	-0.15
SLOPE2	% of 3-8 degree slope area	-0.05	-0.27	0.69
SLOPE3	% of 8-15 degree slope area	-0.34	-0.07	0.33
SLOPE4*	% of 15 degree & over slope area	-0.96	-0.21	-0.06
ELEV1	% of 0-100m elevation area	0.83	-0.17	0.05
ELEV2	% of 100-200 m elevation area	-0.13	0.53	0.03
ELEV3*	% of 200 m & over elevation area	-0.89	-0.23	-0.09
MOUNTAIN	% of mountain and volcano area	-0.90	-0.28	0.01
HILLS	% of hill area	0.03	-0.09	0.43
PLATEAU	% of plateau & tableland area	0.33	-0.07	0.29
LOWLAND	% of low land area	0.66	0.35	-0.39

* Excluded from canonical correlation analysis but canonical loadings are calculated.

Fig. 5. Comparison of the first canonical loadings between 1970 and 1990.

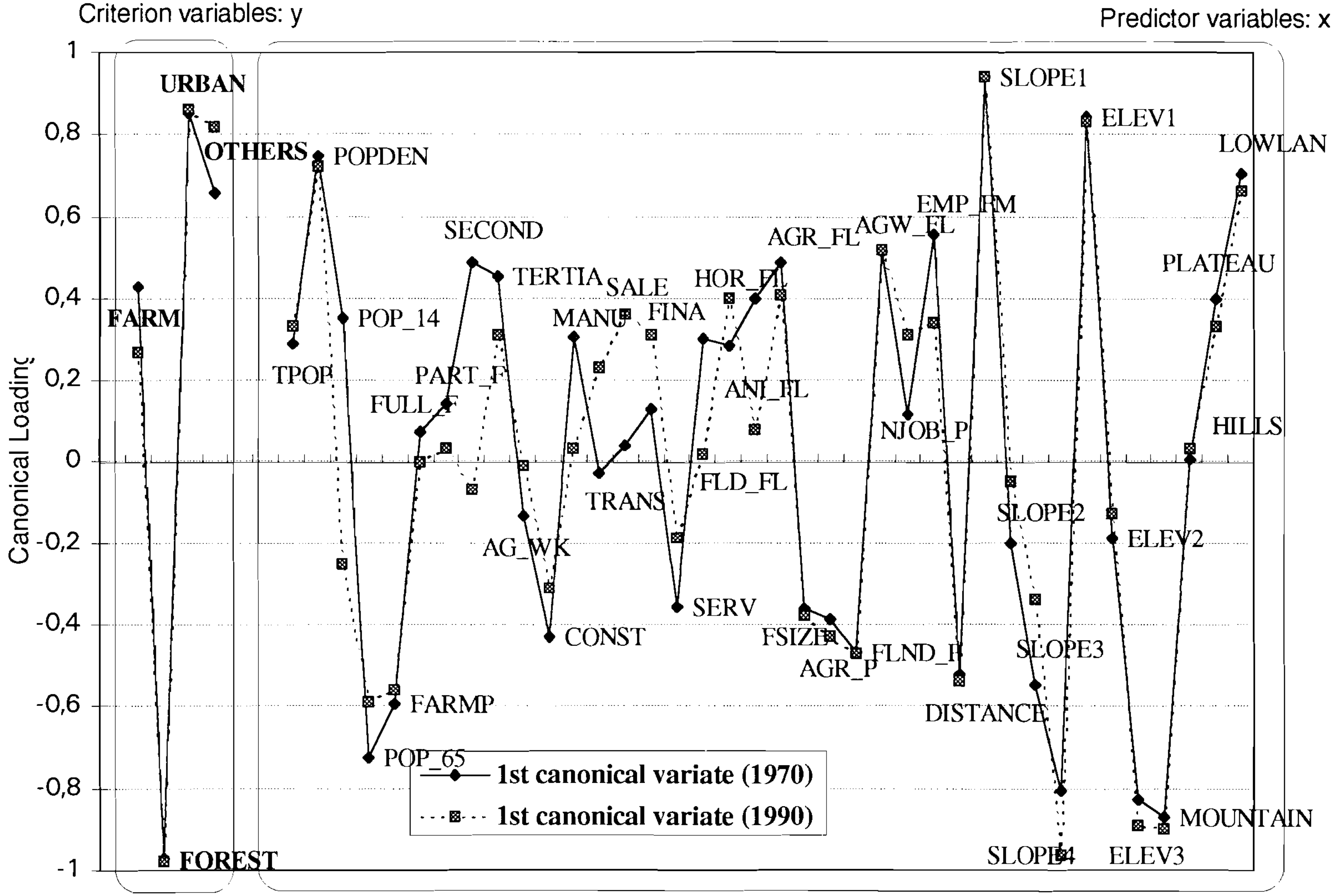


Fig. 6. Comparison of the second canonical loadings between 1970 and 1990.

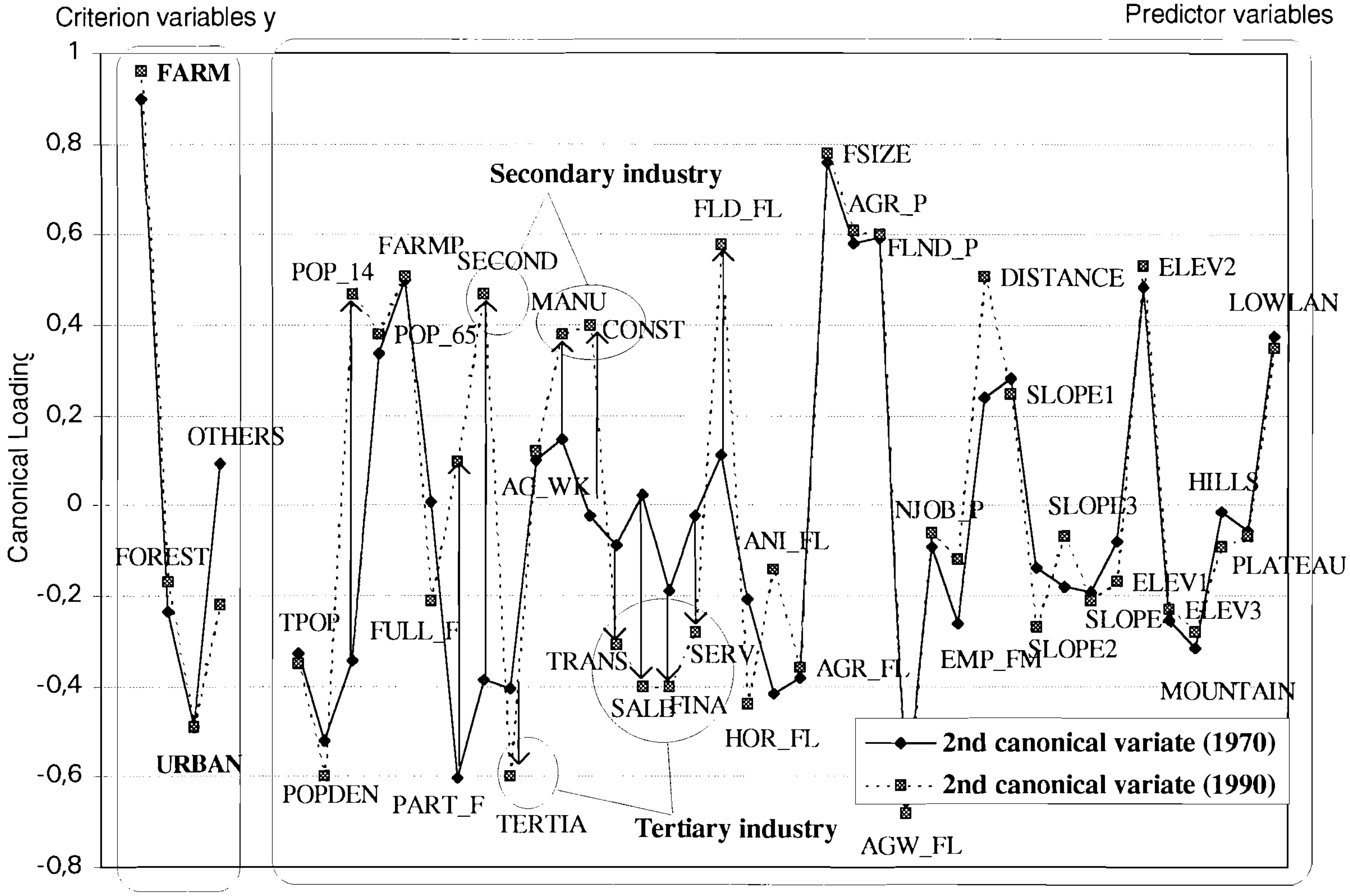
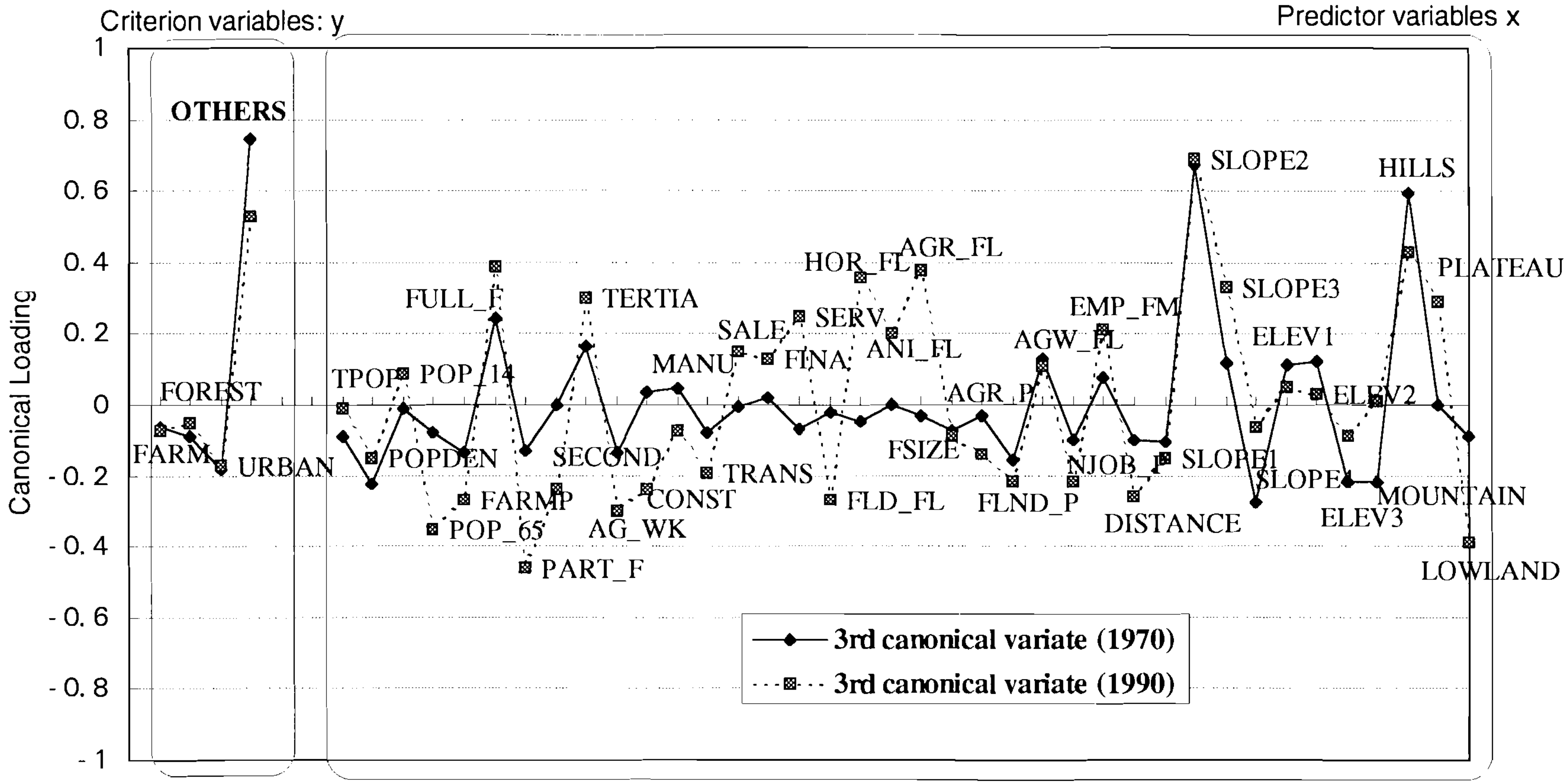


Fig. 7. Comparison of the third canonical loadings between 1970 and 1990.



5. Land-use Changes and Driving forces

5.1 Method of analysis

Even though changes in the land-use structure are small, we wish to clarify the role that socio-economic factors have played in land-use change in the Kansai district. In this section, we focus on temporal changes of farmland and residential land during the study period and try to clarify how well these land-use changes can be explained by the levels and changes of the socio-economic factors during the study period as well as by the geophysical conditions[7]. For this purpose, multiple regression analysis is applied (See Fig. 8). Explanatory variables for the regression model are selected with the step-wise method.

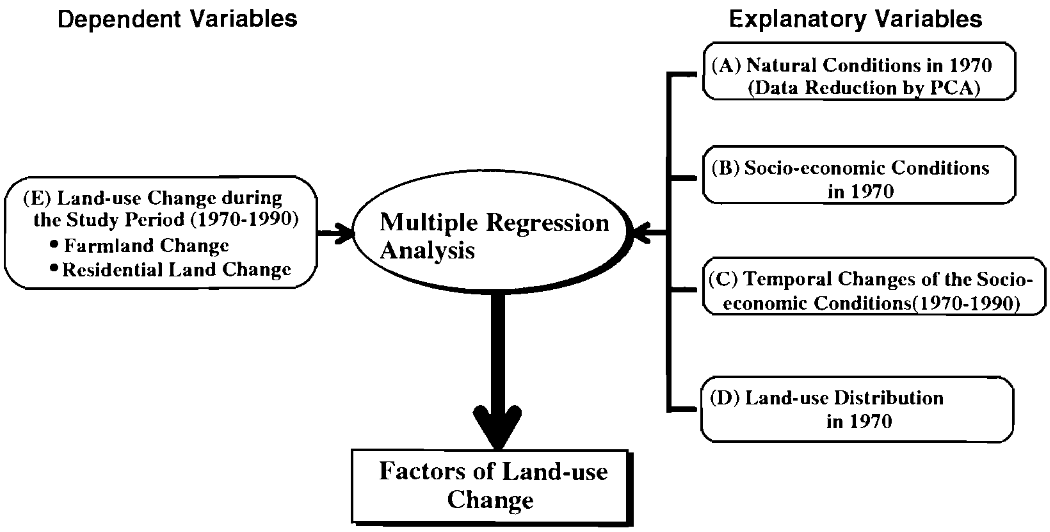


Fig. 8. Framework of Analysis for Land-use Change.

Percentage changes of the major land-use (S_L_i) are calculated by subtracting area percentage of a land category for 1970 (L_i^{1970}) from that for 1990 (L_i^{1990}), as shown in the following expression. Subscript i denotes the land-use categories.

$$S\_L_i = L_i^{1990} - L_i^{1970} \quad (i=1, ..., 4)$$

Table 7 shows the average value and standard deviation of change in percentage area of each land-use category. Farmland and forestry land have decreased during the period whereas residential land and public and other land have increased. Correlation coefficients among the land-use changes are also shown in Table 7. There is no significant correlation coefficient between farmland change (S_FARM) and residential land (S_URBAN)[8].

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[7] Himiyama et al. proposed a list of general socio-economic factors related to land-use change in Japan [Himiyama (ed.), 1992]. Their results also provided us with useful information.

[8] We apply regression analysis instead of canonical correlation analysis due to this lack of significant correlation between major land uses of interest.

Table 7. **Mean and standard deviation of land-use change and correlation coefficients.**

	Mean(%)	S. D.*	S_FARM	S_FOREST	S_URBAN	S_OTHERS
S_FARM : area change of farmland	-4.58	3.01	1.00			
S_FOREST : area change of forestry land	-1.51	4.98	0.06	1.00		
S_URBAN : area change of residential land	1.74	5.12	-0.09	0.01	1.00	
S_OTHERS: area change of public & other land	4.51	7.79	-0.38	-0.67	-0.63	1.00

* : Standard deviation.

The change of land-use during a certain period is considered to be brought about by (A) natural conditions, (B) levels of socio-economic factors at the beginning of the period and (C) their temporal changes during the same period[9]. In addition, the magnitude of change of a certain land use is considered to depend on (D) the percentage of that land-use at the beginning of the period.

Using principal component analysis (PCA), we reduced the more often closely correlated variables available for this analysis[10]. In case of natural conditions, principal components with clear meanings were detected because of the strong correlations among the variables. One the other hand, sets of interesting components were extracted via the PCA of socio-economic indicators and temporal change indicators. However, principal components that have complicated meanings are not suitable as explanatory variables of land-use change. Therefore, for these two groups we retained the original indicators. However, some indicators that have strong correlations with other indicators were excluded from the explanatory variables. In addition, indicators that do not have direct causal relationships to the explained variables were also excluded.

[9] The indicators of the group (C) are calculated by $S\_IND_j = IND_j^{1990} - IND_j^{1970}$ (Subscript j denotes the indicators).

[10] When we set up a strict criterion for variable selection in the step-wise method, selected indicators may frequently change their places with other indicators that have strong correlations with the indicators by initial combinations of the indicators. The major reason for the indicator reduction by PCA is to stabilize the selection of the indicators as well as to avoid the multicollinearity problem.

Principal component analysis of natural conditions

Table 8 shows principal component loadings of natural conditions. In the first principal component, loadings for mountainous topography, steep slope, and high elevation were quite high on the positive side, and those of lowland topography, gentle slope and low elevation were high on the negative side. Therefore the first principal component reveals the difference between mountainous areas with steep slopes and lowland areas with flat land[11]. The second principal component was a "hill" component in which hilly topography and medium slopes were combined. The third principal component was the "plateau" component in which plateau topography and medium elevations were combined. Thus, instead of the original 11 indicators, we carry forward these 3 component: mountain, hill, and plateau.

Table 8. Principal Component Loadings (Varimax Rotated).

	PCA 1	PCA 2	PCA 3
	NATURAL1	NATURAL2	NATURAL3
MOUNTAIN	0.94		
ELEV3	0.94		
SLOP1	-0.92		
SLOP4	0.89		
LOWLAND	-0.81		
ELEV1	-0.73		-0.59
SLOP3	0.45	0.44	
HILLS		0.84	
SLOP2		0.83	
ELEV2			0.87
PLATEAU			-0.47
Pct of Var.	46.7%	17.4%	11.7%
Cum Pct	46.7%	64.2%	75.9%

Note: PC loadings whose absolute values are less than 0.4 are not displayed in this table.

11 The structure of the first principal component is quite similar to the geophysical part of the first canonical variate on the prediction side though the direction is opposite.

Multiple regression analysis

Nine cases were set for each of the target variables, in order to test the explanation ability of each explanatory group, the prediction ability of all the information available at the beginning of the period, the contribution of initial land-use condition and the driving forces of land-use change (Table 9). These explanatory variables are input variables of the regression analysis. Only influential variables will be left through the step-wise procedure.

Table 9. Combinations of dependent and explanatory variables.

		Explanatory variables			
Case	**Dependent variable**	**(A)Natural conditions**	**(B)Socio-economic conditions at the beginning (1970)**	**(C) Temporal changes of (B) during the period (1970-90)**	**(D) Land use at the beginning (1970)**
f-1	Farmland change	✓			
f-2	Farmland change	✓			✓
f-3	Farmland change		✓		
f-4	Farmland change		✓		✓
f-5	Farmland change			✓	
f-6	Farmland change			✓	✓
f-7	Farmland change	✓	✓		✓
f-8	Farmland change		✓	✓	✓
f-9	Farmland change	✓	✓	✓	✓
u-1	Residential land change	✓			
u-2	Residential land change	✓			✓
u-3	Residential land change		✓		
u-4	Residential land change		✓		✓
u-5	Residential land change			✓	
u-6	Residential land change			✓	✓
u-7	Residential land change	✓	✓		✓
u-8	Residential land change		✓	✓	✓
u-9	Residential land change	✓	✓	✓	✓

Table 10. Results of regression analysis for farmland change.

Case	f-1	f-2	f-3	f-4	f-5	f-6	f-7	f-8	f-9
Indicator Group	Natural	Natural Land-use	Socio-economic	Socio-economic Land-use	Change	Change Land-use	Natural Socio-economic Land-use	Socio-economic Change Land-use	All
Multiple Corr. Coefficient	0.52	0.52	0.68	0.78	0.48	0.71	0.78	0.84	0.78
Determinant Coefficient	0.27	0.27	0.46	0.61	0.23	0.50	0.61	0.70	0.61
Natural	NATURAL1 0.52	NATURAL1 0.52					NATURAL1 0.66 NATURAL3 0.17		NATURAL1 0.70 NATURAL3 0.20
Socio-economic			FARMP70 -0.45 TERTIA70 -0.79 AG_WK70 0.42 MANU70 -0.40 SERV70 0.31 AGR70_FL 0.25 AGW70_FL 0.27	PART_F70 -0.31 TERTIA70 -0.41 AG_WK70 0.48 MANU70 -0.38 TRANS70 -0.20 AGR70_FL 0.22 AGW70_FL 0.27			TERTIA70 -0.33 MANU70 -0.36 TRANS70 -0.23 FLD70_FL 0.23 AGW70_FL 0.60	PART_F70 -0.42 AG_WK70 0.64 SERV70 0.23 AGR70_FL 0.29	CONST70 0.25 AGW70_FL 0.58
Temporal changes					S_POPDEN -0.27 S_AG_WK -0.40	S_POPDEN -0.18 S_POP_64 -0.16 S_AG_WK -0.22 S_FSIZE 0.35		S_POPDEN -0.15 S_FARMP 0.21 S_TERTIA 0.21 S_FSIZE 0.43	S_FSIZE 0.39
Land-use				FARM70 -0.54		FARM70 -0.62		FARM70 -0.63	

N. B. Values in the table are standerdized regression coefficients. Shaded parts are indicator groups used as input variables of the regression analysis.

5.2 Farmland change

Table 10 shows the results of the multiple regression analysis whose dependent variable is change of farmland. The shaded parts in the table are the indicator groups used as input variables of the regression model.

Natural conditions

When only natural conditions were used as explanatory variables (**case f-1**), the determinant coefficient of the farmland change model was 0.27[12]. The only indicator of the model was NATURAL1 which shows the difference between steep mountainous areas and flat lowland areas. This means that farmland decrease was relatively small in places where topographical conditions are rough. Although the distribution of farmland at the beginning of the study period was explained by natural conditions[13], change in farmland during the study period could not be explained by natural conditions alone.

The results for **case f-2,** in which the land-use indicator (i.e., the share of farmland at the beginning of the period) was added to explanatory variables, were the same as for case f-1. Thus, the land-use indicator was not adopted.

Socio-economic conditions

The determinant coefficient of the model using socio-economic conditions at the beginning of the period (**case f-3**) was 0.46. This value was larger than that of the above case f-1 using only natural conditions and case f-5 (described below) using only temporal changes of socio-economic conditions.

The indicator with the largest absolute value of standardized regression coefficient was the percentage of employees in tertiary industry (-0.79). The higher the share of tertiary industry at the beginning of the period, the more farmland decrease was accelerated. In the same way, a higher share of employees in manufacturing industry also accelerated farmland decrease (regression coefficient -0.40).

Intensive use of farmland has also made a contribution to farmland conservation. Higher gross farm product and more agricultural laborers restrained farmland decreased (determinant coefficients, 0.25 and 0.27 respectively).

Standardized regression coefficients for the ratio of female agricultural laborers to total agricultural laborers, farm-household ratio and percentage of employees in the service industry were 0.42, -0.45 and 0.31, respectively. If we interpret these regression coefficients literally, then loss of farmland was remarkably high in the areas where male laborers still remained in agriculture at the beginning of the period, "rurbanization" had not progressed[14], and accessibility to urban services was poor. However, we need to interpret the meaning of these coefficients in another way. In 1970 (at the beginning of the study

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[12] When the original 11 indicators of natural conditions were used instead of the principal components, the determinant coefficient of the model hardly changed (0.28).

[13] When the percentage of farmland is the dependent variarble and the natural conditions are explanatory variables, the determinant coefficient is much larger (0.56).

[14] See the footnote 5.

period), Japan was in the middle of the rapid economic growth. The processes of urbanization and industrialization were still going on in the study region. At that time, some areas were already urbanized but others were not. The regression coefficients for gender, household, and service employee idicators reveal that in the areas which had only little experience of urbanization before 1970, the speed of change during the following period was remarkably high compared with those which had already urbanized to some extent before. Therefore we can consider these three coefficients how fare along a region is on the urbanization trajectory[15].

Case f-4 is the model in which land-use indicators are added besides socio-economic conditions. In this case, the determinant coefficient was improved to 0.61. Indicators such as farm-household ratio and percentage of employees in the service industry were dismissed, and percentage of part-time farm household and percentage of employees in the transportation and communication industries were added into the model equation. The negative sign of two new indicators coincided with the expectation that employment in other sectors tends to reduce farmland area.

Temporal changes of the socio-economic conditions

The determinant coefficient of the **case f-5** model was relatively low (0.23). Farmland change cannot be well explained by temporal change indicators alone. The regression coefficient for increase of population density was -0.27 and that for increase of percent of female agricultural laborers was -0.40. The latter indicates that a weakening of the agricultural labor force accelerated the transformation of farmland to other uses[16].

When the land-use indicators were added (**Case f-6**), the determinant coefficient similarly improved to 0.50. In this case, two indicators (change in average farm size and change in percentage of working-age population) were added to the above indicators. It is interesting that expansion of farm size during the study period made a considerable contribution to farmland conservation (regression coefficient, 0.35). This means that while the number of farm households in the study region decreased, some farmland was transferred to the remaining farm households resulting in a change in farm-size structure and farmland conservation. On the other hand, increase in the working-age population accelerated farmland conversion.(regression coefficient, -0.16).

Using information available at the beginning of the period

Case f-7 examined how well farmland change during the period can be explained by all the

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[15] The urbanization trajectory might also be related to the intention to hold farmland, described in section 2. The more an area is urbanized and land prices rise, the more farm households refrain from selling their land.

[16] In the case of f-3, the ratio of female agricultural laborers at the beginning of the period was interpreted as an indicator of the past experience of urbanization. However, the temporal change of the ratio can be interpreted as weakening of the agricultural labor force, the normal meaning of the indicator. Thus the base condition and its temporal change can be interpreted in different ways. Similar phenomena can be found in the case of residential land change described later. The base condition and temporal change of secondary industry act as different factors.

indicators of natural conditions, socio-economic conditions and land use that are available at the beginning of the period. However, as a result of variable selection by the step-wise method, the land-use indicator (i.e., percentage of farmland) was not adopted. Using the other two indicator groups (natural and socio-economic conditions), the determinant coefficient of the model was improved to 0.61.

Among the natural conditions, steep-sloping mountainous conditions (NATURAL1) and mid-level elevation conditions (NATURAL3) were adopted as variables. Farmland decreases were small in these areas. Regression coefficients were 0.66 and 0.17, respectively. On the other hand, *most indicators* in socio-economic conditions were common to those of case f-3 (only socio-economic). However, gross field husbandry product per farmland is adopted instead of gross farm product per farmland, and percentage of employees in the transportation and communication industries is also added. The indicators showing past experience of urbanization such as the ratio of female agricultural laborers, the farm-household ratio and the percentage of employees in the service industry were not adopted in this case.

Socio-economic conditions and their temporal changes

Case f-8 used the three indicator groups of socio-economic conditions at the beginning of the period, their temporal changes during the period, and land use as explanatory variables. The determinant coefficient was the largest among all the cases (0.70). The indicators selected from the socio-economic conditions coincided almost completely with the indicators selected in cases f-3 (only socio-economic) and f-4 (socio-economic and land-use).

In the temporal change group, change in farm-household ratio (0.21) and change in percentage of employees in tertiary industry (0.21) were adopted besides increases in average farm size (0.43) and population density (-0.15). In areas where the decrease of the farm-household ratio during the period was small (that is, "rurbanization" did not advance), farmland decrease was restrained. The growth of tertiary industry during the period also restrained farmland decrease. We deal with this point in the section on residential land change (case u-6).

Prediction of farmland change by all indicators

Case f-9 shows the result of using all the indicators together. Unexpectedly the determinant coefficient (0.61) was less than that of case f-8. This was probably because we set up a strict criterion for variable selection in the step-wise method: the significance level for variable inclusion was set at 5% that for variable exclusion was set at 10%. Also, the multiple correlation coefficient was high due to only a few powerful variables. The indicator of land use was not selected, and only a few indicators of socio-economic conditions and temporal changes were adopted.

Table 11. Results of regression analysis for residential Land Change.

Case	u-1	u-2	u-3	u-4	u-5	u-6	u-7	u-8	u-9
Indicators Group	Natural	Natural Land-use	Socio-economic	Socio-economic Land-use	Change	Change Land-use	Natural Socio-economic Land-use	Socio-economic Change Land-use	All
Multiple Corr. Coefficient	0.55	0.76	0.61	0.70	0.56	0.66	0.85	0.79	0.87
Determinant Coefficient	0.30	0.58	0.37	0.49	0.31	0.44	0.73	0.64	0.75
Natural	NATURAL3 0.55	NATURAL1 -0.61					NATURAL1 -0.61		NATURAL1 -0.56
Socio-economic			TPOP70 -0.51 POP_64 0.26 SECOND70 -0.64 NJOB70_P 0.40	TPOP70 -0.41 POPDEN70 0.85 SECOND70 -0.26 EMP70_FM 0.45			TPOP70 -0.34 POPDEN70 0.82 TERTIA70 0.17 EMP70_FM 0.24	TPOP70 -0.29 POPDEN70 0.77 POP_64 0.37 FINA70 -0.16 NJOB70_P 0.35	TPOP70 -0.24 POPDEN70 0.80 EMP70_FM 0.25
Change					S_TPOP 0.28 S_SECOND 0.54	S_TPOP 0.18 S_TERTIA -0.33		S_TPOP 0.31 S_SECOND 0.37 S_TERTIA -0.22	S_TPOP 0.15 S_TERTIA -0.14
Land-use		URBAN70 -0.87		URBAN70 -1.20		URBAN70 -0.61	URBAN70 -1.68	URBAN70 -1.18	URBAN70 -1.61

N. B. Values in the table are standardized regression coefficients. Shaded parts are indicator groups used as input variables of the regression analysis.

5.3 Residential land change

Table 11 shows the results of multiple regression analysis in which change of residential land is an dependent variable. The results of each case are as follows.

Natural Conditions

Case u-1 used only the indicators of natural conditions. The determinant coefficient of the model was 0.30. NATURAL3, which represents a moderate degree of elevation (100 - 200m), was adopted (regression coefficient, 0.55).

In **case u-2** in which the land-use indicator (i.e., percentage of residential land area at the beginning of the study period) was included as the explanatory variable, the determinant coefficient of the model was greatly improved from 0.30 to 0.58. In this case, NATURAL1 (flat lowland conditions) was selected and the standardized regression coefficient was -0.61. This means that residential land expansion occurred predominantly in the lowland. The regression coefficient for the percentage of residential land was -0.87, indicating that the expansion of residential land was strongly restrained in places where the share of residential land at the beginning of the period was already high. When the results of all the cases using natural conditions are considered, the topographical factor representing the difference between steep-sloping mountain areas and flat lowland areas was the most influential in land-use change of both farmland and residential land.

Socio-economic conditions

Case u-3 is the regression model in which only socio-economic conditions are used. The value of the determinant coefficient is 0.37. In places where the total population at the beginning of the period was comparatively small (regression coefficient, -0.51), and where the share of employees in secondary industry was low (regression coefficient, 0.64), expansion of residential land was promoted. The share of employees in secondary industry had a strong negative correlation with the share of employees in primary industry[17] (correlation coefficient is -0.86). A low percentage of secondary industry at the beginning indicates underdevelopment and lack of urbanization. Thus this indicator reveals the degree of urbanization, described in case f-3[18]. The regression coefficient of non-agricultural jobs per 100 people[19] was 0.40, and that of working-age population[20] was 0.26. Where "pull" power of non-agricultural

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[17] Because this indicator strongly correlates with many other variables, it was excluded from regression analysis.

[18] In the case of farmland change, ratio of female agricultural laborers and farm-household ratio are associated with past experience of urbanization, and in case of residential land change, percentage of employees in secondary industry falls under the same category. It is reasonable that the former represents urbanization on agricultural side and the latter represents that of the industrial structure.

[19] [None-agricultural jobs per 100 people] = [total number of non-agricultural jobs of all business enterprises located in the municipality] ÷ [total population of the municipality] × 100. This indicator represents the relative capacity of non- agricultural employment in the municipality.

[20] Percentage of the population between 15 and 64-year-old to the total population of the municipality.

employment was strong at the beginning of the period and share of economically-active population was high, residential land increased greatly during the following decades.

In **case u-4**, land-use was added to the socio-economic conditions. The determinant coefficient of this model is 0.49. Values of the regression coefficients show that rapid expansion of residential land was brought about in places where population density in 1970 was high (0.85), but size of total population, and share of residential land were relatively small (-0.41 and -1.20 respectively). The regression coefficient for the percentage of employees in secondary industry was -0.26, as in case u-3, expansion of residential land was generally found where secondary industry had not accumulated at the beginning. The number of employees per business firm is the indicator that represents the scale of business enterprise from the viewpoint of employment. The regression coefficient of this indicator was 0.45. In places where the scale of business enterprise had been comparatively large before 1970, expansion of residential land during the period 1970-90 was remarkable.

Temporal changes of the socio-economic conditions

Case u-5 is the case using only indicators of temporal changes in socio-economic conditions. The determinant coefficient of this model is not very large (0.31). But the regression coefficients show that increase of total population and accumulation of secondary industry both made a considerable contribution to expansion of residential land (0.28 and 0.54 respectively).

Case u-6 adds land use at the beginning of the study period as an explanatory variable. Of note, the regression coefficient for "change in percentage of employees in tertiary industry (S-TERTIA)" was negative (-0.33). Since the share of employees in primary industry largely decreased in all areas of the study region during the period from 1970 to 1990, the areas that could not fully develop their secondary industry during the period consequently increased the share of employees in tertiary industry. In other words, the increase of percentage of employees in tertiary industry implies a stagnation of economic activities.

In addition, all the samples were classified into two groups by change in percentage of employees in tertiary industry (S_TERTIA). The table below shows a comparison of real growth rate for the two groups. Real increase of both secondary and tertiary employees of the group 2 (the high S_TERTIA group) was smaller than that of group 1 (the low S_TERTIA group). In other words, in areas where the share of employees in tertiary industry has increased, absolute numbers of employees in secondary and tertiary industries have not increased very much. Furthermore, I located the samples whose share of tertiary industry greatly increased during the period on the study area map, and confirmed the inference concretely.

This indicator shows not only the share of the economically active population , but also the share of population with fertility.

Table 12. Comparison of growth rates of employees by group with different temporal change in percentage in tertiary industry

	Temporal change in percentage of employees*			Growth rate of employees**		
	In primary industry	In secondary industry	In tertiary industry (S_TERTIA)	In primary industry	In secondary industry	In tertiary industry
Group1***	-19.6%	6.3%	13.3%	-71.7%	93.3%	147.8%
Group2****	-27.8%	5.9%	21.9%	-72.7%	80.7%	114.2%

* Temporal change in percentage of employees(%) = [percentage of employees in 1990(%)] – [percentage of employees in 1970(%)].
** Growth rate = [{employees in 1990} ÷ {employees in 1970} - 1.0] × 100(%).
*** Group 1 : low S_TERTIA group. (The temporal change in percentage of employees in tertiary industry is small.)
**** Group 2 : high S_TERTIA group. (The temporal change in percentage of employees in tertiary industry is large.).

Using information available at the beginning of the period

Case u-7 is the case in which the model was built with the three indicator groups of natural conditions, socio-economic conditions and land use. The determinant coefficient of this case is high (0.73). The combination of the adopted indicators was almost the same as case u-4 (socio-eocnomic + landuse). Expansion of residential land was conspicuous in places where population density at the beginning of the period was high and share of flat area was large, but also where total population was not very high, and residential land was not prevalent. In addition, expansion of residential land occurred in the areas in which the average scale of business enterprise at the beginning of the period was already large.

Socio-economic conditions and their temporal changes

Case u-8 is the case in which socio-economic conditions, their temporal changes during the period, and land use were used as explanatory variables. Most adopted socio-economic indicators resembled those of the other cases. The share of employees in the financial industry, which gave negative effect (-0.16), appeared uniquely in this case. As for indicators of temporal changes, it is interesting that the regression coefficient for the share increase in secondary industry was positive (S_SECOND, 0.37) but that for the share increase of employees in tertiary industry was negative (S_TERTIA, -0.22). The former indicates development of secondary industry, whereas the latter implies ates stagnation of economic activities. The share of residential land area created a negative feedback effect on the expansion of residential land, as in the other cases.

Prediction of residential land change by all indicators

Case u-9 shows the highest determinant coefficient (0.75) among all the models for residential land change. Moreover, all the indicators adopted into the model appeared at least twice in the other cases. Therefore, this case shows the most robust result. The result can be interpreted as follows: Residential land increases occurred in areas with a variety of flat topography, high population density, large-scale of business enterprises, low total population, and a comparatively low share of residential land at the beginning of the period. Furthermore, population increase during the period was also an important factor for residential land expansion. The increase of percentage of employees in tertiary industry during the period was a factor restraining residential land expansion as is similar to the above cases u-6 and u-8.

5.4 Comparison of determinant coefficients

In order to estimate the contribution of each indicator group, we compared the determinant coefficients of the four indicator groups: natural conditions, socio-economic conditions, their temporal changes and land use. In case of the models for farmland change, the socio economic conditions dominate, (case f-3, 0.46), followed by natural conditions (case f-1, 0.27), and temporal changes (case f-5, 0.23). Land use itself explained the least (square of correlation coefficient, 0.16). In the case of the models for residential land change, socio-economic conditions also explained the most (case u-3, 0.37), followed by temporal changes (case u-5, 0.31), and land-use (square of correlation coefficient, 0.31). The last was natural conditions (case u-1, 0.30).

Each indicator group contributes to explaining land-use change. However, the socio-economic structure at the beginning of the period prescribed the subsequent land-use change of both farmland and residential land the most. This conclusion coincides with the results of the second canonical variate of the land-use structure in section 4.

5.5 Factors of land-use change

A new classification for the factors of land-use change

A driving force of land-use change is a factor that causes land-use change. In determining the driving forces by statistical methods, we found a wide variety of factors. Therefore we developed a new classification scheme for the factors of land-use change (See Figure 9).

The socio-economic driving forces can be divided into two groups. In one group, which we call the "affecting side", are the exogenous forces that bring about land-use change from outside the study area. They are the driving forces in the ordinary sense. The other group is the factors on what we call the "moderating side". These are endogenous characteristics of the area that allow adaptation to force impinging from the outside. We term the factors on the moderating side "counter forces". Since natural conditions and the initial state of land use do not directly cause land-use change by themselves, it may not be suitable to call these "driving forces" in the ordinary sense. However, our analysis has shown that both the natural condition and the initial land-use state are also important elements in regard to land-use change. In the new scheme, they are treated as a separate factor group.

The actual land-use changes are thus a result of the interaction between the driving forces on the affecting side and the counter forces on the moderating side, given the natural conditions and the initial land-use state.

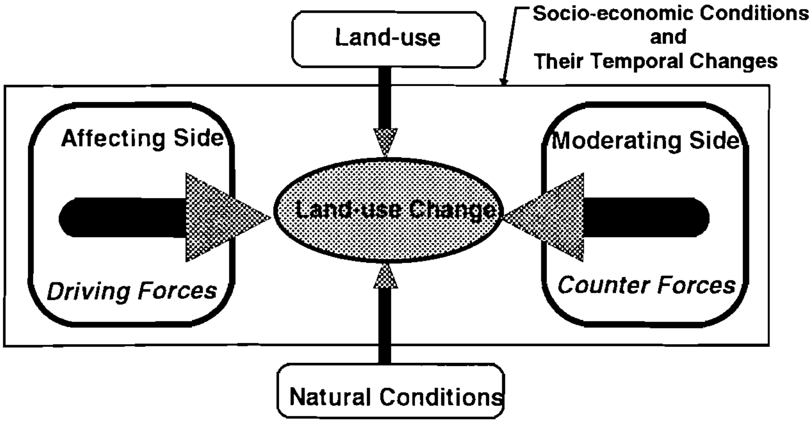

Fig. 9. Basic scheme for the factors of land-use change.

Factors of farmland change

Based on this new scheme, we qualitatively analyze all the factors of farmland change identified in the regession analysis. Since indicators adopted in each individual case varied due to the initial indicators input in the regression analysis and by the criteria for variable selection in the step-wise method, we combined all the cases together. We then selected the indicators that appeared at least twice in Table 10. Figure 10 shows not the indicators themselves but the factors that those indicators imply. Shaded boxes in the figure indicate temporal change factors and unshaded boxes are baseline indicators at the beginning of the study period.

Driving forces of farmland change

The socio-economic driving forces at the beginning of the period were the *initial levels of industrial activities*. Decrease of farmland was promoted in places with high accumulation of tertiary industry. In addition, accumulations of manufacturing industry and transportation industry, which utilize relatively large land areas, also promoted farmland decrease. The most important driving force in the temporal change group is the *increase of population pressure* during the study period. As expected, an increase of population density promoted farmland decrease.

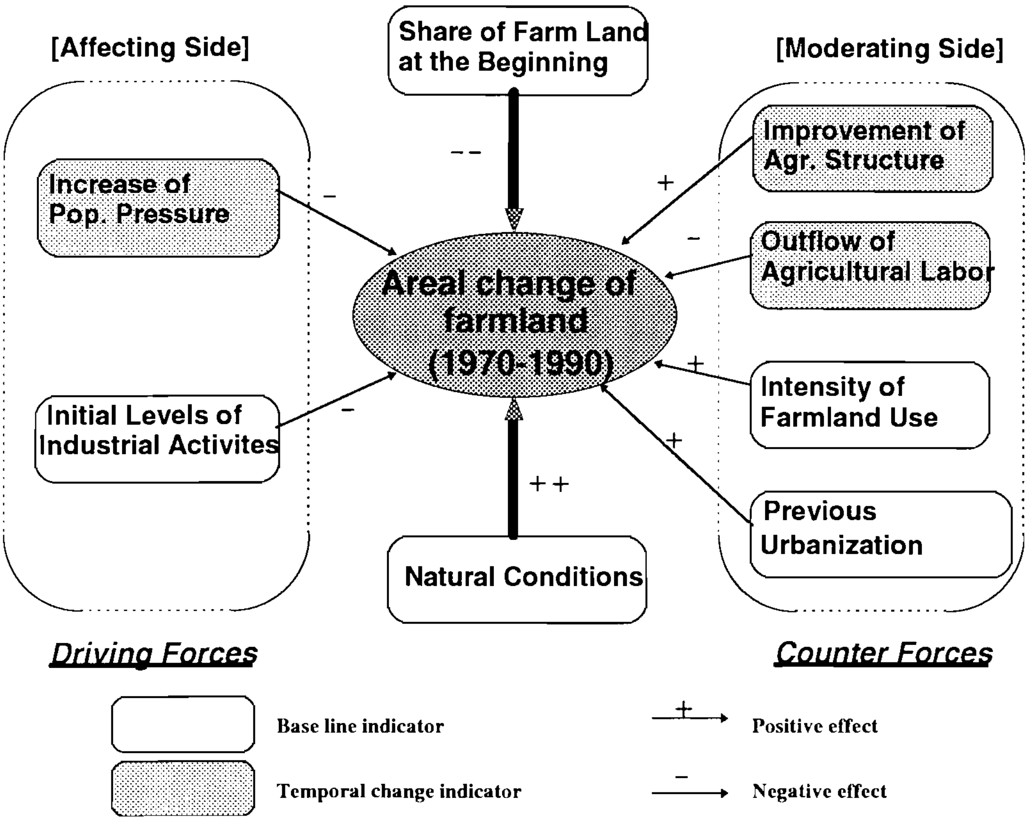

Fig. 10. Factors of farmland change in the Kansai district.

Counter forces of farmland change

The factors on the moderating side were related to the way that farm households utilize land. Two counter forces were detected in the socio-economic conditions at the beginning of the period. The first one is the *intensity of farmland use*, which is associated with the number of agricultural laborers per farmland and the gross farm product per farmland[21]. This counter force slowed the speed of farmland decrease. The second one is the *previous urbanization* associated with the ratio of female agricultural laborers, the farm-household ratio and the percentage of employees in the service industry. High values of these indicators at the beginning of the period mean that the area had already experienced urbanization to some extent before the base year. In such areas, losses of farmland during 1970-1990 was not large. Conversely, in the areas which had not experienced severe urbanization, the changes were apt to become quite big.

Two counter forces were detected in the temporal changes. The first one is *improvement of agricultural structure*. Increase of average farm size made a considerable contribution to conservation of farmland. The second is the *outflow of labor force from agriculture to non-agriculture*. Increases in part-time farming and increases of female ratio of agricultural laborers during the period weakened the agricultural labor force, and as a result, farmland decreases were promoted.

[21] In case f-7, gross field husbandry product per farmland was adopted instead of gross farm product.

Natural and land-use conditions on farmland change

In the natural condition group, mountain topography was associated with a contribution to conservation of farmland. Hill topography appeared as a restraint against farmland decrease in two cases. Therefore urbanization avoided such areas.

The regression coefficients for land use (i.e., the percentage of farmland at the beginning of the study period) in all cases were negative and their absolute values were relatively large (See cases f-4, f-6 and f-8 in Table 10). Therefore the share of farmland at the beginning had a strong negative feedback effect on the expansion of farmland during the subsequent period.

Comparing the coefficients for natural conditions and land use in the farmland change model shown in Table 10, we find that natural conditions were preferentially adopted when both were used in the model; the land-use indicator was adopted only when natural conditions were not included in the explanatory variable set. From this, we understand that the distribution of farmland at the beginning of the period was a proxy for the natural conditions. When we consider that the distribution of current farmland is a long-term consequence that people testing the natural conditions and carefully selecting suitable land for farming, this substitution relationship between the farmland distribution and the natural conditions is readily understandable.

Factors of residential land change

Figure 11 shows the factors of residential land change. The indicators which appeared more than or equal to twice in Table 11 are taken into consideration in the same way those in Figure 10.

Driving Forces of residential land change

On the affecting side, two driving forces were detected in the socio-economic conditions at the beginning of the period. The first one is the *high population pressure*. Both high population density and high percentage of working-age population promoted the expansion of residential land during the subsequent period. The second socio-economic driving force is the *non-agricultural employment capacity* which indicates the number of non-agricultural jobs per 100 people and the number of employees per business enterprise. Large amounts of non-agricultural jobs and large employment in business enterprises at the starting point accelerated residential land expansion during the subsequent period.

In the temporal change group, three driving forces were extracted. Two were the *increases of total population* during the period and the *development of secondary industry*. Increases of both these factors promoted residential land expansion. The third factor was the increase of percentage of employees in tertiary industry. The real meaning of this indicator was the *stagnation of economic activities*, as mentioned in case u-6 and u-8. This means that expansion of residential land was limited in areas where industrial activities were stagnant.

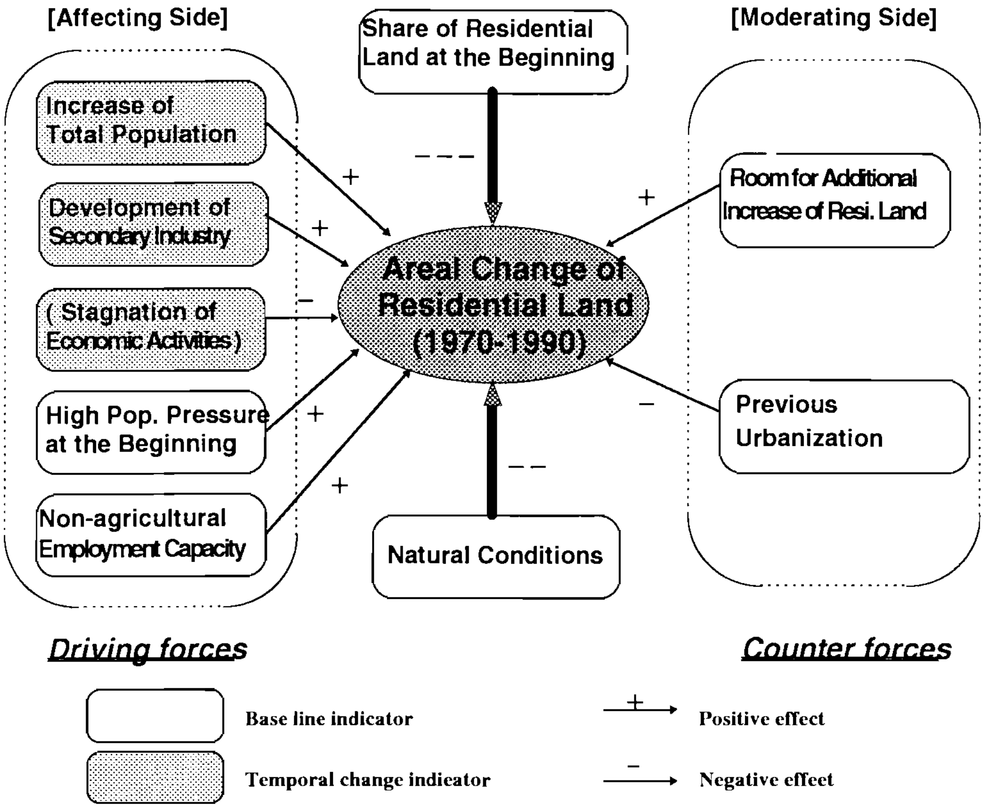

Fig. 11. Factors of residential land change in the Kansai disrict.

Counter forces of residential land change

Two factors were detected on the moderating side. Both relate to socio-economic conditions at the beginning of the period. First, total population size had a negative effect on the expansion of residential land. By the way, percentage of residential land acted as a strong negative feedback on residential land expansion. These indicators can be considered as *room for additional increase of residential land.* Second, the share of employees in secondary industry in the base year (1970) had a negative effect on residential land expansion, i.e., a low percentage of secondary industry in the base year accelerated residential land expansion. This factor can be understood as the *previous experience of urbanization via the industrial structure* (See case u-3).

Natural and land-use conditions on residential land change

The principal component that represents "flat lowland" was selected among the natural conditions[22]. This indicator represents the topographic suitability for residential land. The regression coefficients for residential land were negative and large (See cases u-2, u-4, u-6 and u-8 in Table 11). So this land-use

[22] The flat lowland factor is the same factor as the mountain topography but the direction (sign of the regression coefficient) is opposite.

indicator had a negative effect on residential land expansion[23].

When either the natural conditions or the land use were used as explanatory variables, only one indicator was selected in each case. When both indicator groups were used, one indicator was selected from each group respectively. Therefore, it is inferred that the distribution of residential land contains important heterogeneous information that cannot be substituted for natural conditions unlike the case of farmland change.

[23] The effect of city planning, which has regulated new urban development since 1968, is inferred in this negative feedback effect of residential land.

6 Summary

In this paper, we analyzed both the distribution and the temporal change of land-use in the Kansai district, Japan using statistical methods. A summary of the results follows.

(1) A consistent structure of relationships between land-use distribution and natural and socio-economic conditions in the Kansai district were extracted by the canonical correlation analysis. The most fundamental component on the land-use side was the component that discriminated unmanaged land (forestry land) from managed land (the other land uses). This land-use variate strongly corresponded to the canonical variate showing topographical differences between mountain and lowland areas. On the other hand, the canonical variate that represented the difference between farmland and residential land corresponded to the socio-economic factor that represented the level of economic activity based on agriculture at the farm and local levels.

(2) By comparing the results of the statistical analysis of the 1970 and 1990 data, we tested the temporal stability of the above structure of land-use distribution. Though some interesting structural changes were found in the socio-economic factors, the structure was temporally stable during the study period. Furthermore, the geophysical factors and the specific socio-economic factors revealed to be of importance as stable factors for future land-use change. This result reinforces our conclusion that the land-use structure of the Kansai district is coherent, and also provides fundamental knowledge for predictive model development[24].

(3) Factors identified as important to farmland change and residential land change were examined by multiple regression techniques. The degrees of contribution of four indicator groups (natural conditions, socio-economic conditions at the beginning of the period, their temporal changes during the period and land-use at the beginning) were compared. Socio-economic conditions at the beginning of the period made the largest contribution in cases of both farmland change and residential land change.

(4) A new conceptual scheme for land-use change was proposed. This scheme consists of four parts: exogenous factors on the affecting side that are true "driving forces" in the ordinary sense, endogenous factors on the moderating side now termed "counter forces", natural conditions, and land use in the base year of the study period. Such conceptual scheme for land-use change is similar to the well known PUSH/PULL theory in the field of migration analysis. In this scheme the land user, is properly positioned in the center of the land-use change processes. The adoption of this scheme also highlights the differences between the counter forces for change, and the driving forces.

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[24] The project team of LU/GEC, Japan developed a basic land-use change model based on this temporal stability of the land-use structure [Kagatsume et al., 1996].

(5) As expected, a variety of population factors and economic activities were detected as driving forces. Some counter forces were also identified. Several indicators, which made the interpretation of the results rather complicated, were re-interpreted as the previous urbanization. In addition, the existence of highly motivated farm households made a considerable contribution to farmland conservation. In the case of residential land change, population and land-use indicators were grouped in order to explain the potential for additional increase of residential land use at the beginning of the period. Both natural conditions and starting land use also contributed to land-use change.

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