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Association between Urban Socio-Environmental Characteristics Including Travel Behavior, and Health Performance

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Abstract

Understanding the urban environment and the health status of residents is necessary for appropriate administrative services and regional management. This study used indicator scores derived from the area statistics of cities in the Tokyo metropolitan area to identify factors that affect health status. Indices were classified into two groups: health-related and non-health-related. The index values of each group served as the observed variables and were statistically standardized. The relationship between the two groups was analyzed using canonical correlation analysis. The results indicate that social infrastructure and daily travel behavior affect the health status of residents, possibly by promoting physical activity. Furthermore, characteristics of the urban environment and travel behavior were strongly associated with the ratio of deaths due to lifestyle-related diseases.

Keywords

Urban environment; travel behavior; health indicator; land use; geographic information system

1. Introduction

Physical and mental health status is related to various social factors. The major social factors influencing the well-being of the human population must be determined not only to promote individual health, but also to reduce the difference in health status among populations or regions. The world's urban population has been increasing. According to a report by the United Nations, the urban population will increase from 51.6% of the world's population in 2010, to 59.9% in 2030. Therefore, understanding the urban environment and the health status of residents will become even more important for establishing appropriate administrative services and regional management.

Urban expansion associated with highway construction and suburban development is closely related to the progress of motorization. This has, however, reduced physical activity due to a decrease in walking and may contribute to the increased risks of lifestyle diseases and decreasing age trends observed in recent years. Given the negative effects of motorization, such as traffic congestion and CO_2 emissions, opting for physical activity-based transport like walking or cycling may improve public health and reduce traffic problems [1]. Many studies have focused on the associations between health status, travel behavior, and physical activity [2-4]. Furthermore, the association between neighborhood environments and physical activity and their influence on public health, transportation planning, and environmental design have been widely explored [5-7]. Based on a review of studies on environmental factors affecting physical activity, Sallis et al. [8] reported that population density had a consistent positive consistently correlation with walking trips. Sallis et al. [9] also revealed that better-connected street networks, higher residential and employment densities, more diverse land uses, and easier access to public transport contribute to walkable neighborhood environments. Moreover, the relationship between transport modes and self-rated health has been examined [10, 11]. Physical activity is beneficial in decreasing the risk of obesity and several other health issues such as cancer and diabetes [11]. Health issues require an integrated analysis that incorporates multiple factors related to the environment, transportation, and many other personal and social living conditions [12]. Li et al. [12] conducted a pathway analysis that revealed the potential benefits of community living environments and active travel behaviors on body mass index and health.

Factors influencing health, as determined by mortality indicators, were investigated [13-19]. In addition to research on the association between mortality indicators and socioeconomic and/or sociocultural factors, Berrebi and Silber [14] performed a global study to analyze the relationship between the development of a country and the cause of death. Mackenbach et al. [18] also used geographical patterns of mortality to examine the cause of death in areas with higher mortality rates.

Although associations between individual attributes, neighborhood environments, travel behaviors factors and health status have been examined from various points of view, further studies are required to reveal the degree to which health is affected by each factor and the relationships among these factors. This is required for conducting comparisons of population-based health among different areas. Using diverse indicators from area statistics and identifying these factors within units of a certain population level can provide insights into several areas with varying situations. Due to the recent progress in digitalized information, data points previously excluded from analyses due to difficulties in capturing and comparing these factors, can be included in new studies. Similarly, statistical models integrating multiple factors, including health indicators, have increasingly been used to attribute health outcomes to multiple risk factors [20]. The impact of several factors on population-level health can only be fully understood when indicators of the built environment and travel behavior are combined with traditional indicators, such as socioeconomic status.

In Japan, owing to a rapidly aging population and lifestyle changes, lifestyle-related diseases accounted for 60% of all causes of death and 30% of all medical expenses in 2004, indicating that the increase in lifestyle-related diseases has become a serious threat to human health. Because commuters currently do not engage in exercise as they travel, there is a strong association between health status and travel behaviors [21]. In the U.S., physically inactive lifestyles are responsible for approximately 200,000 deaths yearly; thus, physical inactivity can be considered a public health crisis [8]. The health effects of transportation activities must be investigated from the perspective of obesity as work trips may provide an excellent opportunity to increase physical activity [22].

This study aimed to identify factors affecting health status using indicator scores derived from each city's area statistics in the Tokyo metropolitan area of Japan. We selected various elements of population health and urban characteristics from several existing statistics to serve as health status indicators. Additionally, we identified new indicators of land use and travel behavior and calculated their scores for each city. Using these indicator scores, we analyzed the association between population health and urban characteristics, including the travel behaviors of inhabitants.

2. Materials and Methods

2.1 Study Area

The study area comprised nearly the entire Tokyo metropolitan area in Japan, including 189 cities of which all the data required for this study, are available. Administrative boundaries were set to include large areas of Tokyo, Kanagawa, Chiba, and Saitama prefectures, and smaller areas of Ibaraki prefecture. The area had a population of more than 30 million at the time of the 2015 National Census, accounting for approximately 25% of Japan's population. Furthermore, the total surface area under investigation was approximately 7,300 km^2, accounting for approximately 2% of that of Japan. According to a report released by the United Nations Statistical Office, the Tokyo metropolitan area is ranked as the world's largest urban agglomeration in terms of the population [23].

2.2 Indicators for Analysis

This study was designed based on the assumption that many factors, including environmental, socioeconomic, and early life conditions, individual actions, and medical care, affect health [20]. We therefore sought to obtain information on important factors from diverse data. While selecting indicators as variables for the analysis, we adopted many indicators that were considered to be linked to health among the inhabitants. In this study, 62 indicators that could be directly obtained or developed for analysis, were selected. The environment, socioeconomic status, travel behavior, and health data, which are the sources of these indicators, are described below.

Because health is an inherently comprehensive issue, identifying it as an index can be challenging. Therefore, welfare statistics from demographic data that directly address the health problems in Japan were selected as health-related indicators in this study. Descriptive statistics for all variables used in this analysis are provided in Table 1.

Table 1 Descriptive statistics of the indicator variables.

	Mean	Std. Dev.	Min	Max
Built environment variables				
Proportion of area used for mountains or wildernesses	13.15	18.12	0	96.16
Proportion of area used for rice fields	7.42	12.51	0	54.42
Proportion of area used for farmlands	10.49	8.74	0	46.57
Proportion of area used for industrial plants	3.67	3.78	0.03	33.07
Proportion of area used for low-rise residences	18.94	8.21	0.47	41.66
Proportion of area used for mid-to-high-rise residences	4.56	5.18	0.00	26.05
Proportion of area used for commercial facilities	6.65	4.67	0.10	28.20
Proportion of area used for roads	12.85	4.75	0.59	32.12
Proportion of area used for parks or green spaces	5.53	4.01	0.13	18.50
Proportion of area used for rivers or lakes	3.81	3.72	0.13	19.06
Number of retail stores per capita	8.12×10^{-3}	7.07×10^{-3}	3.48×10^{-3}	8.66×10^{-2}
Number of restaurants per capita	5.74×10^{-3}	9.41×10^{-3}	1.38×10^{-3}	1.01×10^{-1}
Number of large-scale retail stores per capita	1.62×10^{-4}	1.88×10^{-4}	0	2.32×10^{-3}
Number of department stores or general merchandise stores per capita	1.83×10^{-5}	1.66×10^{-5}	0	1.68×10^{-4}
Number of hospitals per capita	4.41×10^{-5}	3.47×10^{-5}	0	3.83×10^{-4}
Number of clinics per capita	7.80×10^{-4}	8.82×10^{-4}	2.00×10^{-4}	1.12×10^{-2}
Number of senior care facilities per capita	7.62×10^{-5}	7.58×10^{-5}	0	7.42×10^{-4}
Number of childcare facilities per capita	1.21×10^{-4}	4.23×10^{-5}	4.10×10^{-5}	3.41×10^{-4}
Socio-economic variables				
Proportion of population under 15 years old	13.1	1.9	7.4	19.3
Proportion of population over 65 years old	17.3	3.4	9.1	40.6
Proportion of households formed by nuclear families	61.0	8.6	36.3	75.8
Proportion of households formed by people living alone	29.3	10.7	10.2	57.9

Proportion of agricultural, forestry, and fisheries workers	1.8	2.2	0.01	12.7
Proportion of service workers	71.8	7.3	46.1	87.6
Proportion of unemployed individuals	5.59	0.89	2.91	8.68
Number of employed individuals working in own municipality per capita	1.95×10^{-1}	5.17×10^{-2}	1.13×10^{-1}	3.90×10^{-1}
Number of private cars per capita	2.96×10^{-1}	8.73×10^{-2}	5.51×10^{-3}	5.85×10^{-1}
Number of medical doctors per capita	2.05×10^{-3}	3.30×10^{-3}	2.03×10^{-4}	3.73×10^{-2}
Number of medical pharmacists per capita	2.56×10^{-3}	5.80×10^{-3}	0	7.37×10^{-2}
Number of building fires per capita	2.39×10^{-4}	1.60×10^{-4}	0	1.89×10^{-3}
Number of crimes recorded per capita	1.62×10^{-2}	8.85×10^{-3}	2.05×10^{-3}	1.07×10^{-1}
Floor area per household	81.1	16.4	50.0	128.9
Population density (per square kilometer)	6187.9	4762.3	27.8	19924.8
Sanitation coverage rate	86.5	18.2	25.9	100.0
Travel behavior variables				
Trip time by railway or subway per capita	19.05	5.10	1.01	40.15
Trip time by bus or tram per capita	0.80	0.61	0.00	3.07
Trip time by car per capita	6.88	3.81	1.48	25.15
Trip time by motorcycle per capita	0.41	0.19	0.00	1.21
Trip time by bicycle per capita	2.02	0.83	0.31	4.09
Trip time by walk per capita	2.97	0.62	1.13	5.62
Health variables				
SMR for all death causes (male)	96.2	11.0	72.5	161.9
SMR for all death causes (female)	101.5	11.1	56.1	166.7
SMR for malignant neoplasms (male)	97.3	8.3	75.8	120.2
SMR for malignant neoplasms (female)	101.0	8.9	63.8	128.6
SMR for heart disease (male)	100.1	17.4	68.0	188.0
SMR for heart disease (female)	104.3	18.0	43.3	209.5
SMR for cerebrovascular disease (male)	99.8	25.4	61.3	336.6
SMR for cerebrovascular disease (female)	102.0	19.3	52.1	256.3

SMR for pneumonia (male)	99.8	20.1	59.0	219.8
SMR for pneumonia (female)	107.6	26.7	39.2	245.2
SMR for liver disease (male)	105.7	48.0	24.4	493.3
SMR for liver disease (female)	109.1	27.1	42.4	199.1
SMR for kidney failure (male)	93.1	22.5	38.8	168.3
SMR for kidney failure (female)	94.3	25.9	43.6	222.8
SMR for senility (male)	109.3	65.6	30.7	475.1
SMR for senility (female)	107.5	58.9	27.6	568.8
SMR for suicide (male)	83.2	17.4	45.1	178.9
SMR for suicide (female)	99.1	22.8	37.6	187.4
Total fertility rate	1.20	0.15	0.74	1.52
Spontaneous fetal death rate (per 1000 birth)	12.41	2.43	2.3	20.3
Infant death rate (per 1000 birth)	2.77	0.95	0.5	7.3
Divorce rate (per 1000 people)	2.10	0.35	0.82	3.26

SMR: standardized mortality ratios

2.3 Data

2.3.1 Built Environment Data

Land use data were obtained from the Tokyo City Planning Geographic Information System [24] and Digital Map 5000 [25], available in ArcGIS 10.0. The land-use composition of each city was derived from the original polygon data, which were spatially differentiated. The System of Social and Demographic Statistics in Japan collects statistical data from various fields and can be used to understand living conditions [26]. We identified eight types of facilities as factors affecting health status and included the number of facilities per capita as indicators in our analyses.

2.3.2 Socio-Economic Data

We obtained 16 socioeconomic data items from the Social and Demographic Statistics System and used the per-capita value of these items instead of percentages in our calculations.

2.3.3 Travel Behavioral Data

A "trip" represents a one-way passage from an origin to a destination when a person travels for a purpose. The number of "trips" between the origin and destination, based on representative transportation data from the Person Trip Survey (PT data), was utilized to examine the actual travel behavior of 2 % of the residents in the Tokyo metropolitan area [27]. The priority order among the representative transportation modes was as follows: rail, bus, car, motorcycle, bicycle, and walking.

The total travel time was determined by multiplying the number of trips by the average travel time for each transportation mode among the areal units. To focus on the behavior of residents, these trips were confined to passages starting from home and commuting to work or school, or moving for business or private purposes. The average travel time per person was obtained by dividing the total trip time by the area's total population. This travel time was underestimated because it was normalized to the total population rather than to the actual number of travelers.

2.3.4 Health-Related Data

Index values were used for statistical analyses of data concerning health status, such as cause-specific mortality rates by sex and total fertility rates from 2003-2007 [28]. Standardized mortality ratios (SMR) and total fertility rates were corrected using empirical Bayes estimators among these indices.

2.4 Statistical Analysis

The Pearson correlation coefficients of all index pairs were calculated to provide an overview of the relationships between the indices. After that, to examine the factors affecting health status, all indices were classified into one of two groups: health-related and remaining indices. The index values of each group, which served as the observed variables, were statistically standardized, and their relationships were derived using canonical correlation analysis. A linear composite variable summarizing the characteristics of the data within each set was obtained, and the combination of variables was determined using the maximum correlation coefficient of the composite. These correlation coefficients and composite variables are termed the canonical correlation coefficient and canonical variable, respectively. As canonical variables did not correlate, canonical correlation analysis was used to determine how health-related indices are affected by other urban characteristics through a wide range of index values. Hereafter, IBM SPSS Statistics 20.0, Syntax, was used for canonical correlation analysis.

3. Results

3.1 Geographical Distributions of the Variable

The following variables used for analysis are highlighted in Figure 1: “population density,” “proportion of the area used for commercial facilities” “trip time by railway or subway per capita,” “SMR for all death causes,” and “total fertility rate." Population density decreased with increasing distance from the center of the metropolitan area. However, small populations exist in limited residential areas owing to the accumulation of government and business offices in the inner city area of Tokyo.

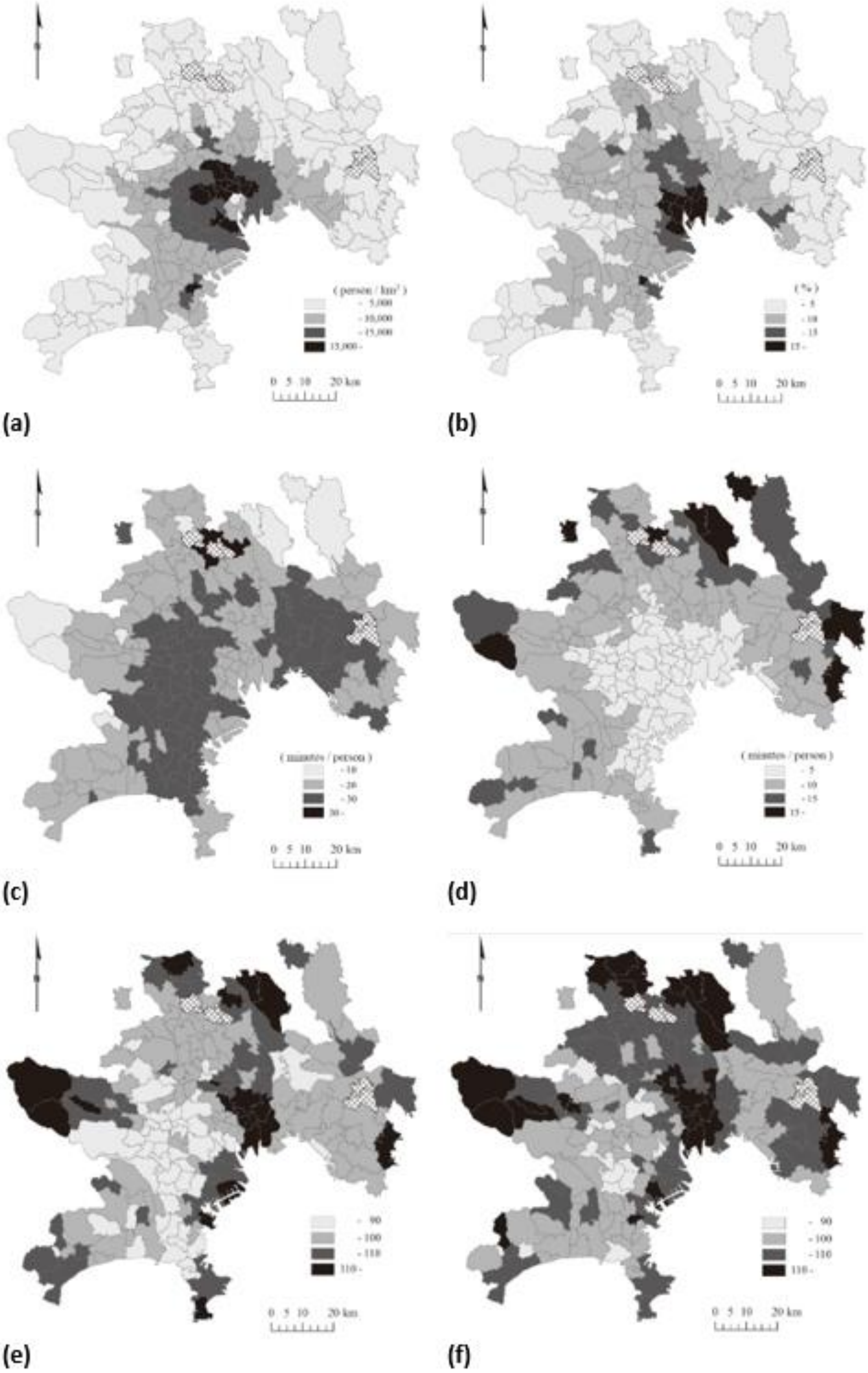

Figure 1 Spatial distribution of indicator values. **(a)** population density; **(b)** proportion of area used for commercial facilities **(c)** trip time by railway or subway; **(d)** trip time by car; standardized mortality ratios (SMR) for all causes of death in **(e)** males and **(f)** females.

As demonstrated by the trend associated with this characteristic geographical distribution, the trip time by railway or subway was relatively long in circular zones at a certain distance from the central area, as residents commute from these zones to the center of the metropolitan area. Furthermore, the trip time by railway or subway may be shorter in the outer region of this zone, as the travel time to work decreases with the increasing number of people commuting to major local cities that are not in central Tokyo. Furthermore, the likelihood of using a car increased as railways decreased.

The areas filled by hatched lines in Figure 1 indicate a lack of data on travel behavior, land use, or data that could not be collated by area.

3.2 Simple Correlation between the Variables

A strong correlation was found among multiple urban characteristic indices, particularly commercial status. The correlation coefficients between “proportion of the area used for commercial facilities” and “proportion of the area used for roads”; “number of retail stores” and “number of restaurants”; “number of retail stores” and “number of large-scale retail stores”; “number of restaurants” and “number of large-scale retail stores”; and “numbers of large-scale retail stores” and “number of department stores or general merchandise stores” were 0.79, 0.95, 0.93, 0.92, and 0.73, respectively.

This result may be attributed to the strong positive correlation among multiple indices in urban environments, especially those related to commerce. In addition, the correlation coefficient between "floor area per household" and "mid-to-high-rise residence" and "trip time by car" was -0.73 and 0.82 respectively, representing a high degree of freedom of land use in low-density urban areas rather than describing the housing situation related to income.

None of the non-health-related indicators was strongly correlated with specific causes of death, and no correlation coefficients were greater than 0.7. In addition, no strong correlations were found between the different causes of death. Conversely, among male and female causes of death, a strong relationship was found with "heart disease," "cerebrovascular disease," "pneumonia," and "senility," having correlation coefficients of 0.7 or higher. Sex differences were observed in these diseases, unlike other causes of death such as "liver disease" and "suicide,” for which the correlation coefficient was less than 0.3.

3.3 Canonical Correlation between the Groups of Variables

If the null hypothesis of lack of association between canonical variables is rejected at a significance level of 1 %, nine canonical dimensions representing the two sets of corresponding canonical variables are obtained. Each canonical dimension was ranked in descending order based on the canonical correlation coefficient from the first to the ninth dimension.

Table 2 shows the canonical correlation coefficient, contribution rate to each group of variables, and canonical loading of all original variables. Canonical loadings are defined as the correlations between the original variables and their corresponding canonical variates, and are known as canonical structure correlations. The absolute values of the canonical loadings, greater than 0.3, are shown in grey in Table 2.

Table 2 Canonical variates and canonical loadings for each indicator.

Canonical variates	1	2	3	4	5	6	7	8	9
Canonical correlation coefficient	0.967	0.944	0.919	0.842	0.787	0.765	0.711	0.685	0.678
Significance probability	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
Contributing rate	0.202	0.078	0.055	0.028	0.031	0.037	0.018	0.018	0.014
Cumulative contribution rate	0.128	0.206	0.261	0.289	0.320	0.357	0.375	0.393	0.407
Built environment variables									
Proportion of area used for mountains or wildernesses	-0.434	0.417	0.210	0.029	0.332	0.218	-0.183	-0.177	-0.042
Proportion of area used for rice fields	-0.293	0.127	0.087	-0.399	-0.500	-0.322	-0.150	0.191	-0.045
Proportion of area used for farmlands	-0.450	-0.202	0.168	-0.131	0.031	-0.358	0.024	-0.092	-0.191
Proportion of area used for industrial plants	-0.123	-0.272	-0.492	0.093	0.120	0.222	-0.060	0.129	0.112
Proportion of area used for low-rise residences	0.349	-0.364	0.188	0.136	-0.018	0.164	0.247	0.236	0.085
Proportion of area used for mid-to-high-rise residences	0.731	0.105	-0.026	0.193	0.155	-0.044	0.182	-0.103	0.094
Proportion of area used for commercial facilities	0.617	-0.057	-0.415	0.208	-0.026	0.027	0.135	-0.051	0.003
Proportion of area used for roads	0.629	-0.262	-0.271	0.162	-0.065	-0.006	0.196	0.048	0.023
Proportion of area used for parks or green spaces	0.437	-0.118	-0.109	0.158	-0.013	0.106	0.054	-0.171	0.102
Proportion of area used for rivers or lakes	-0.130	-0.020	-0.218	-0.300	-0.108	-0.182	0.014	0.247	-0.150
Number of retail stores per capita	0.330	0.227	-0.242	-0.074	-0.094	-0.042	0.134	-0.209	-0.065
Number of restaurants per capita	0.404	0.145	-0.251	0.043	-0.060	-0.055	0.084	-0.166	-0.008
Number of large-scale retail stores per capita	0.330	0.063	-0.095	0.009	-0.115	-0.105	0.189	-0.152	-0.026
Number of department stores or general merchandise stores per capita	0.217	-0.119	-0.111	-0.023	-0.262	0.055	0.158	-0.024	0.185
Number of hospitals per capita	0.037	0.268	-0.060	0.123	0.011	-0.061	0.253	-0.025	0.029
Number of clinics per capita	0.414	0.177	-0.091	-0.017	-0.025	0.012	0.156	-0.178	0.015
Number of senior care facilities per capita	-0.415	0.694	0.095	0.166	0.155	0.274	0.016	0.008	-0.137
Number of childcare facilities per capita	-0.377	0.497	-0.017	0.077	0.059	-0.017	-0.039	-0.197	0.196
Socio-economic variables									
Proportion of population under 15 years old	-0.621	-0.690	0.184	-0.057	-0.059	-0.016	0.005	-0.005	-0.029
Proportion of population over 65 years old	-0.077	0.734	-0.112	-0.137	0.156	0.220	0.069	-0.035	-0.127

Proportion of households comprising nuclear families	-0.579	-0.261	0.377	0.031	-0.042	0.059	-0.154	0.063	-0.107
Proportion of households comprising single residents	0.738	0.043	-0.255	0.220	0.083	0.107	0.158	-0.080	0.126
Proportion of agricultural, forestry, and fisheries workers	-0.509	0.242	0.021	-0.444	-0.024	-0.393	-0.052	-0.024	-0.037
Proportion of service workers	0.761	0.010	0.191	0.206	0.065	0.314	0.149	-0.137	0.011
Proportion of unemployed individuals	-0.107	0.121	-0.531	0.095	-0.095	0.056	-0.042	0.037	0.079
Number of employed individuals working in own municipality per capita	-0.295	0.139	-0.469	-0.114	0.024	-0.128	0.036	-0.114	-0.162
Number of private cars per capita	-0.435	0.051	0.101	-0.109	-0.004	-0.311	-0.226	-0.071	-0.068
Number of medical doctors per capita	0.428	0.123	-0.061	-0.024	-0.015	-0.036	0.157	-0.167	-0.039
Number of medical pharmacists per capita	0.327	0.068	-0.054	-0.045	-0.040	-0.016	0.135	-0.133	-0.051
Number of building fires per capita	0.300	0.242	-0.346	0.010	-0.053	-0.169	-0.009	-0.124	-0.166
Number of crimes recorded per capita	0.311	-0.043	-0.288	0.086	-0.249	-0.119	0.148	-0.144	0.004
Floor area per household	-0.612	0.045	0.227	-0.304	-0.215	-0.192	-0.010	-0.197	-0.197
Population density	0.725	-0.025	-0.221	0.181	0.050	0.160	0.236	0.045	0.088
Sanitation coverage rate	0.527	-0.275	0.048	0.211	0.340	0.342	-0.149	-0.102	0.225
Travel behavior variables									
Trip time by railway or subway per capita	0.464	-0.297	0.348	0.062	-0.112	0.233	0.087	0.051	0.179
Trip time by bus or tram per capita	0.431	0.022	-0.274	0.045	0.394	0.237	0.156	-0.028	0.287
Trip time by car per capita	-0.714	0.134	0.111	-0.195	-0.160	-0.313	-0.142	-0.052	-0.040
Trip time by motorcycle per capita	-0.016	-0.348	-0.031	0.070	0.376	0.104	0.035	0.202	-0.106
Trip time by bicycle per capita	0.159	-0.277	-0.177	0.223	-0.265	0.124	0.066	0.226	-0.178
Trip time by walk per capita	0.232	-0.181	0.029	0.142	0.068	0.318	-0.096	-0.058	-0.041
Contributing rate	0.128	0.121	0.182	0.050	0.045	0.035	0.033	0.031	0.022
Cumulative contribution rate	0.128	0.249	0.431	0.481	0.526	0.561	0.594	0.625	0.647
Health variables									
SMR for all causes of death (male)	-0.372	0.480	-0.701	-0.018	-0.167	0.153	-0.004	0.082	-0.070
SMR for all causes of death (female)	-0.337	0.504	-0.428	0.093	-0.227	0.084	-0.176	0.199	-0.177
SMR for malignant neoplasms (male)	0.085	-0.096	-0.693	-0.285	-0.194	0.113	-0.085	0.111	-0.102
SMR for malignant neoplasms (female)	0.471	-0.095	-0.562	-0.033	-0.138	0.244	-0.071	0.098	-0.201
SMR for heart disease (male)	-0.256	0.255	-0.456	0.276	-0.537	0.100	0.140	0.218	-0.092

SMR for heart disease (female)	-0.350	0.345	-0.235	0.359	-0.403	-0.013	-0.151	0.146	-0.064
SMR for cerebrovascular disease (male)	-0.550	0.615	-0.350	0.212	-0.125	0.121	0.141	0.150	0.052
SMR for cerebrovascular disease (female)	-0.485	0.519	-0.289	0.101	-0.053	0.033	-0.002	0.224	-0.114
SMR for pneumonia (male)	-0.522	0.453	-0.113	0.156	0.011	0.277	-0.368	-0.047	-0.007
SMR for pneumonia (female)	-0.396	0.350	-0.065	0.208	-0.275	0.129	-0.510	0.110	-0.146
SMR for liver disease (male)	0.215	0.065	-0.755	-0.148	0.179	0.326	-0.103	0.047	0.366
SMR for liver disease (female)	-0.123	0.040	-0.438	-0.283	-0.048	-0.043	0.214	0.102	0.065
SMR for kidney failure (male)	-0.287	0.160	-0.382	-0.113	-0.117	-0.079	-0.006	-0.084	-0.041
SMR for kidney failure (female)	-0.219	0.286	-0.218	-0.199	0.011	-0.212	-0.299	0.482	-0.207
SMR for senility (male)	-0.374	0.162	-0.170	-0.462	0.050	-0.335	-0.083	-0.052	-0.003
SMR for senility (female)	-0.333	0.272	-0.136	-0.436	-0.093	-0.215	-0.042	-0.073	0.105
SMR for suicide (male)	-0.365	0.404	-0.557	-0.064	-0.051	-0.264	-0.003	-0.097	0.044
SMR for suicide (female)	0.093	0.229	-0.214	-0.100	-0.425	-0.208	-0.165	0.020	0.000
Total fertility rate	-0.757	-0.612	-0.103	-0.068	-0.024	0.091	-0.002	0.007	-0.005
Spontaneous fetal death rate (per 1000 birth)	-0.104	0.045	-0.296	0.069	0.260	-0.232	0.076	0.325	-0.130
Infant death rate (per 1000 birth)	-0.071	0.166	0.033	-0.141	0.077	-0.164	0.213	0.267	0.344
Divorce rate (per 1000 people)	0.051	-0.419	-0.768	0.293	0.046	-0.184	0.003	-0.145	0.091

SMR: standardized mortality ratios

The analysis results among the nine canonical variates with significant correlation coefficients are discussed based on canonical loadings. We considered the contribution ratio of each canonical variate, especially from the 1st to 3rd canonical variates, which have particularly high canonical correlation coefficients. Because canonical loadings represent the relative correlation strength, the plus-minus sign of their values does not influence their interpretation. In other words, cities with characteristics contradicting the results interpreted here are regarded as opposing health situations. In terms of the impact on the results based on the contribution ratio, the 4th canonical variates and below were viewed as low priority compared to the 1st to 3rd variates, despite their significance. The 1st, 2nd, and 3rd canonical variates results are interpreted below.3.3.1 The 1st Canonical Variates

According to the canonical loadings of land use, cities typified by the first canonical variates don't contain many natural environments. Instead, they are highly urbanized, with a high population density, frequent use of public transportation, and access to many commercial facilities. The overall mortality ratio in these cities tended to be low. This indicates that the state of urbanization is related to the health of residents.

Based on health indicators, as the overall mortality ratio (including each cause of death) tended to be low, the state of urbanization (including the availability of facilities and frequency of public transportation use) was related to the health of residents. In addition, the very low fertility rate might be due to the high proportion of single-person households living in urban centers in this area. This result also demonstrates that if the mortality rate of women due to "malignant neoplasms " is high, and if women tend to spend more time at home than men, the effects of the living environment on health must be verified via further investigations.

3.3.2 The 2nd Canonical Variates

Within the 2nd canonical variable, regarding land use, many "mountains or wilderness" and relatively few "residential areas" exist. The characteristics of travel behavior include low use of "motorcycles," a low "proportion of the population under the age of 15," a high "proportion of the population aged 65 and over," and numerous nursing care facilities. Accordingly, the second canonical variable represents urban areas with many elements of "old new towns," aging suburban areas centered on housing complexes, and suburban areas with declining birthrates and aging populations. Based on health indicators, including "death due to cerebrovascular disease," the overall mortality rate in these areas was high. Furthermore, the sex-based differences between causes of death were small. Overall, the results represented the health status of an aging community.

3.3.3 The 3rd Canonical Variates

Regarding the 3rd canonical variable, few "industrial plants" and "commercial facilities" exist due to the characteristics of land use. Many individuals use "the railway and subway" for commutes, and few persons "work in their municipality." In addition, this variable is characterized by a low "unemployment rate," a low number of "building fires," and a low number of "crimes recorded," thereby indicating high safety. In terms of family type, many "nuclear family households" were recorded; thus, many regional elements were centered in suburban residential areas with comfortable living environments. In terms of health indicators, the ratio of all deaths, including "deaths from malignant neoplasms," "heart disease," and cerebrovascular disease," which are attributed to lifestyle, was low. In addition, the total number of deaths was the lowest here among the canonical variables. In contrast, the "divorce rate" and percentage of deaths attributed to "suicide" was low. Accordingly, socioeconomic factors that affect health status are relatively strong.

4. Discussion

The results of this study indicate that a lifestyle that relies on automobiles and lacks opportunities to use public transportation may lead to health risks, such as malignant neoplasms, heart disease, and cerebrovascular disease. In this study, differences in the cause of death associated with each relationship were small. However, the values of the canonical loadings related to urban characteristics represent each city within that canonical variable, and the differences between canonical variables are evident. In previous studies, factors affecting health were examined using principal component analysis [14] and canonical correlation analyses on the relationship between health and socioeconomic indicators [15, 19]. This study objectively evaluated the effect of the urban environment and travel behaviors over a wide area, on the health of residents. This study, 62 index items were used for the canonical correlation analysis, and nine significant combinations with large canonical correlation coefficients were found. However, the overall contribution rate and explanations were relatively small. Because many indicators were simply used as variables, the diversity of the original urban characteristics was reflected.

Although this study covered a wide area, a single metropolitan region spread over a wide distance was the target of the assessment. Accordingly, a high degree of similarity was assumed between cities for items not explained by the indices considered in this study, including natural environmental factors such as weather. However, depending on the situation within the city, further scrutiny of the representation of the indicators may be required. The results of this study suggest that the degree of health as defined by the mortality ratio is markedly influenced by population structure, urban environment, and travel behavior. Comparisons with other metropolitan areas on different regional scales should be performed in the future.

Collecting data for this study required various sources from the same period. It was therefore complicated as the update interval of travel behavior and built environment data was longer than that of socioeconomic and health data. Because this study analyzed municipalities, local changes are unlikely to have a significant impact. However, a limitation of this study is that the possible variability in the type of residents, especially in areas with large-scale developments, was not reflected in the data and should not be ignored. Therefore, although we recognize the importance of collecting panel data and analyzing changes over time, simultaneous data collection is challenging; hence, the analysis of change over time is difficult within the framework of this research.

In Japan, walking and cycling are important modes of transportation used to access train and bus stations [21]. In this study, walking and cycling did not have a considerably higher significant impact on health status than the other factors. However, because the survey data in this study aggregated typical means of transportation, the time required to commute to work or school included the time spent on foot or riding a bicycle from home or the workplace to the transportation hub. Accordingly, increased time spent on public transport may indicate increased time spent on foot and bicycles. Further research is required to clarify the association between public transportation and physical activity-based commutes.

5. Conclusions

By targeting Japan's metropolitan areas, we analyzed the relationships between urban characteristics, including travel behavior and health status, based on the aggregate values of indicators such as regional statistics for each municipality. The analysis results suggest that an urban environment with advanced social infrastructure that promotes physical activity among residents and daily travel behavior, such as public transportation, affects residents' health status. In particular, the aggregated data revealed that the characteristics of the urban environment and travel behavior were strongly associated with the ratio of deaths due to lifestyle-related diseases.

The results of the canonical correlation analysis showed that extracting types of cities with specific characteristics based on their relevance to health conditions, is possible from the perspective of urban planning. Similarly, various socio-environmental characteristics are associated with various health risks. The results obtained in this study provide guidance and quantitative information to promote appropriate health policies for different social and environmental situations compared to other regions.

In Japan, the lack of access to public transportation, such as abolishing bus routes in population-declining areas, is problematic. Decreased opportunities to walk or use public transportation can be risk factors that reduce the daily physical activity of residents. Therefore, the results of this study provide new insights into urban and regional planning from a health promotion perspective.

Author Contributions

The author accomplished all the research work of this study.

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Competing Interests

The author has declared that no competing interests exist.

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