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Full Paper

AN URBAN EVALUATION METHOD FOR THE REALIZATION OF SUSTAINABLE COMPACT CITIES

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Abstract

Cities integrate diverse social, economic and political activities and are an engine for economic development. However, the concentration of population, traffic, and energy use has led to deteriorating urban environments through such impacts as air pollution, traffic congestion, and the heat island effect. Also, cities contribute to global warming through the carbon dioxide released from concentrated energy use. The objective of this study was to evaluate the potential for developing compact cities as a key factor for the development of sustainable cities. To achieve this objective, we compiled currently available data on the features of cities in a new database, and conducted an assessment of the quality of urban environments in relation to population density - an important factor to be considered when planning compact cities. The results showed that the creation of a compact city requires stable economic activity and a certain population density. The results also indicate that an excessive population concentration may lead to increased environmental loads in terms of, for example, air pollution, traffic conditions, food and energy consumption, and waste production. Thus, the realization of a compact city demands an appropriate spatial compactness.

KEYWORDS: *sustainable city, compact city, environmental burden*

1. Introduction

Some 48% of the world's population, or roughly 3 billion people, live in concentrated urban areas (United Nations, 2004). Both developed and developing countries have this concentration of urban populations. Traffic congestion and automobile pollution, the heat island effect from the concentrated use of energy, and large emissions of carbon dioxide all contribute to global warming (IETC, 2003).

Since beginning of 1990s, the concept of the compact city has been regarded as a key factor for the development of sustainable cities in developed countries, especially Europe. Compact cities might provide resource and energy conservation benefits. However, there is considerable debate over the viability and effectiveness of compact cities; people have a preference for low-density residential areas and are concerned that their quality of life does not deteriorate.

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Also, the complexity and diversity of the compact city concept have compounded the intricacy of the discourse.

The main objective of this research is to evaluate the potential for developing compact cities using city profile indicators. The definition of a compact city adopted for this research is a city that has an appropriate space and functional density, a low environmental load and maximum amenity. To assess the potential for creating compact cities for sustainable development, a framework that can be used to comprehensively evaluate cities is needed with reference to their current status and the history of their many problems.

Thus, this study has three subsidiary objectives:

1) Using literature available on sustainable urban development, prepare a new framework for evaluating urban development
2) Organize information related to the characteristics of cities in developed and developing countries, and investigate the potential trajectories for socio-economic development that would produce sustainable cities
3) Construct a framework for the comprehensive evaluation of cities, including their environmental aspects, examine the characteristics and advantages of compact cities, and assess compact cities for their environmental impact and sustainability using relevant indicators. This process includes an analysis of the relationship between the environment, society, economy, and population density to clarify the function of population density within a compact city.

In this paper, we first review previous research on urban assessment and proposed frameworks for comprehensive urban assessments that consider a city's economy, society, environment and compactness. This provides our framework for evaluating cities. Then, so we can discuss the availability of compact cities, we conduct an urban environmental assessment using various indicators related to population density. This is presented in our Results and Discussion. Urban assessments in which various indicators are evaluated in the same analysis are difficult and have many limitations because of a lack of data. We conducted multilateral urban assessments centered on population density and determined the potential for creating compact cities. Finally, we present our research findings, which illustrate the requirements of a compact city.

2. A framework for evaluating cities

2.1 Urban problems in developed and developing countries

In previous assessments of the environmental aspects of cities, analyses have been typically conducted using indices such as the urban environmental indicators of the OECD (1978). Table 1 presents current economic, social, and environmental problems in cities of developed and developing countries taken from our literature survey.

2.2 History of urban assessments

Many assessments of the quality of urban areas have been conducted (ICLEI, 2000), and the

Table 1. Economic, social, and environmental urban problems

Aspect	Developed countries	Developing countries
Economy	Concentration of information and financial functions	Extreme poverty
Society	Stable population, aging society and fewer children	Increasing population
	Donut phenomenon (emptying city centre)	Population shift into cities, and growth of slums
	Urban congestion (motorization)	Lack of transport infrastructure, and chronic traffic congestion
	Decreasing per capita area of park land	Water shortages and lack of sanitation facilities
	Diversification of crime	Frequent violent crime
Environment	Air pollution (NOx, SPM, and photochemical smog)	Severe air pollution (NOx, SPM, photochemical smog)
	Decrease in urban green areas, shift to underground waterways	Loss of greenery and natural environment
	Heat islands and accelerated atmospheric warming	Air, ground, water and noise pollution
	Increasing CO_2 emissions and energy use	Lack of infrastructure for clean water and sewage
	Greater flooding in cities	Rising sea level and increased flooding

pressure-state-response (PSR) framework has been proposed as a methodology for establishing internationally consistent indicators (OECD, 1993). Consequently a variety of indices to measure the quality of urban environments have been developed (Haan *et al.*, 2000).

Also, as global environmental problems have become more serious, much knowledge has been accumulated on indicators such as those proposed for sustainable development and those that consider both the state of the economy and environment (Segnestam, 2002). Useful concepts for constructing a framework for urban assessment are shown in Table 2. In addition to conventional assessment frameworks covering economic, social and environmental aspects, some urban assessments also examine compactness. For example, there have been feasibility studies of super high-rise buildings and studies of the efficient use and disposal of water, sewage and wastes in high-rise buildings (Architectural Institute of Japan, 2000). As urban environmental problems have become more serious, investigations of spatial amenity in cities have also been conducted (New Zealand Ministry for the Environment, 2000). Here, 'amenity' means not just physical comfort, but includes human livability, as expressed by a comfortable living environment and space.

2.3 Urban assessment with consideration of compactness

In this study, we adopt the assessment targets used in conventional urban assessments, namely, economic, social and environmental functions, while analyzing proposed frameworks for urban assessments that consider urban compactness to evaluate the potential for developing compact cities (Figure 1).

Economic aspects are represented by measures such as gross regional product (GRP), residents' income, and city finances. Social aspects can be expressed by factors such as the quantity and quality of water and sewage lines and other sanitation infrastructure, the quantity and quality of transport infrastructure, education facilities and levels, and the incidence of crime. Indicators adopted for environmental aspects include power sources, energy consumption, CO_2

emissions, water pollution, air pollution and waste production. These three aspects not only interact as part of a vigorous city, but also cause urban problems. Therefore, the basic framework of the urban assessment used in this study to evaluate the prevalence of compact cities is a mechanism that comprehensively assesses the compactness of a city on the basis of its population density, transportation density, and density of economic activity.

Table 2. Examples of indicators for comprehensive urban assessments

Name	Coordinator	Assessment	Indicators	Reference
Urban environmental indicators	OECD	Housing, service & employment, environment & pollution, society & culture	Broad environmental indicators to measure quality of life	OECD, 2002
World urban indicators program	UN Center for Human Settlements	Assessment of sustainability of cities	30 quantitative and 9 qualitative indicators	UN-Habitat, 2002
Urban Audit	European Union	Measurement of progress in the sustainable development of cities	5 fields, 33 indicators	EC, 2000
Urban footprint	York, Liverpool city councils	Energy, water, food, resources, urban land use as land area equivalents	Index for comprehensive assessment of cities from environmental and economic perspectives	Barrett and Scott, 2001; Barrett *et al.*, 2002
Environmental sustainability indicators	World Economic Forum	Progress in development of environmental policies by country	22 core indicators (compiled using 67 variables)	WEF, 2002
World's major cities 2000	Tokyo city(30 cities)	Multifaceted assessment of urban activities and management	Index of urban society, economics, management, and finances	SSCMCW, 2000

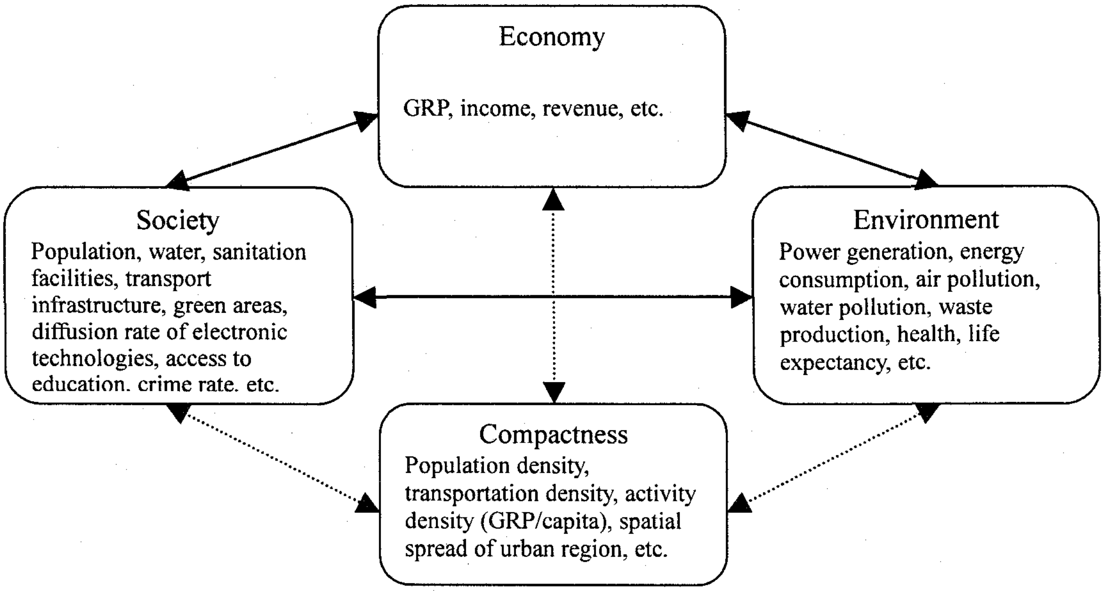


Figure 1. A framework for the comprehensive assessment of cities

3. Results and Discussion

3.1 An indicator-based environmental assessment of world cities

(1) The relationship between city size and the environment

The analysis of world cities in this study relies primarily on social and economic data from the United Nations Human Settlements Programme (UN-Habitat) (2002), power consumption and waste production data from Major Cities of the World 2000 (Secretariat of the Summit Conference of Major Cities of the World, 2000), and traffic data from the International Sourcebook of Automobile Dependence in Cities 1960-1990 (ISADC) (Jeffrey and Felix, 1999). Figure 2 illustrates the relationship between Population or GRP and socio-economic conditions using environmental indicators, such as the extent of water and sewage systems, the mortality rate for children 5 years of age or younger, average life expectancy, energy consumption, waste production, and transport-related factors such as commuting distance and commuting time.

In terms of the coverage of water supply and sewerage systems, the mortality rate and average life expectancy, a clearer improvement was seen with an increase in economic activity (GRP) than with population growth. Specifically, when the GRP surpassed US$1.5 billion per year, the coverage of both the water supply and sewage systems exceeded approximately 80 percent of the city. Similarly, when the GRP surpassed US$1.0 billion per year, the infant mortality rate fell to less than approximately 0.02 with the exceptions of Ankara (0.042), Rio de Janeiro (0.040), and Bangkok (0.033). When GRP was less than US$1.5 billion per year, life expectancy varied widely (males: 50–80 years, females: 50–85 years), but when GRP rose above 1.5 billion US dollars per year, life expectancy stabilized for both men and women (men: 62–75 years, women: 73–83 years). Average life expectancy is influenced by various factors, including the human environment, natural environment, diet and culture. However, increases in economic activity bring better sanitation and medical facilities, improved nutritional conditions, and improved quality of life, all of which are assumed to affect the length and stability of the average life expectancy.

Energy consumption grows in direct proportion to the increase in a city's population. However, in New York and Tokyo, where the population exceeds 7.5 million, energy consumption is very high - some 2 to 4 high as that in other cities with the same population size. Although there was some variation in the amount of waste produced, a similar trend was seen with energy consumption. Since energy consumption and waste production depend on different social and living standards, we examined the relationship between GRP and waste production in the cities of New York and Berlin, which have a similar economic status. This revealed that New York had a much higher energy consumption (about 3.2 times) and waste production (about 3.5 times) than Berlin. Even considering that New York's population is roughly 2.2 times larger than Berlin's, because of the similar level of economic activity in the two cities, it is presumed that energy consumption and waste production are affected not only by lifestyle, but also by city form and structure. These results suggest that a lifestyle, urban form and structure that rely on a low consumption of energy and other resources may be required to keep huge metropolises from exceeding a certain population level. Also, large variations were found in the relationship between commuting distance and time with population and GRP, and no specific trends are seen as population or GRP increases. This is due to the strong impact of city size, city structure and density on the transportation environment of a city.

The above analysis indicates that a certain level of economic growth is needed to achieve a comfortable standard of living, while the creation of a sustainable city requires a lifestyle, city form, and city structure that can be maintained with a low use of energy and other resources. Thus, the structure and density of a city must be considered in addition to its size.

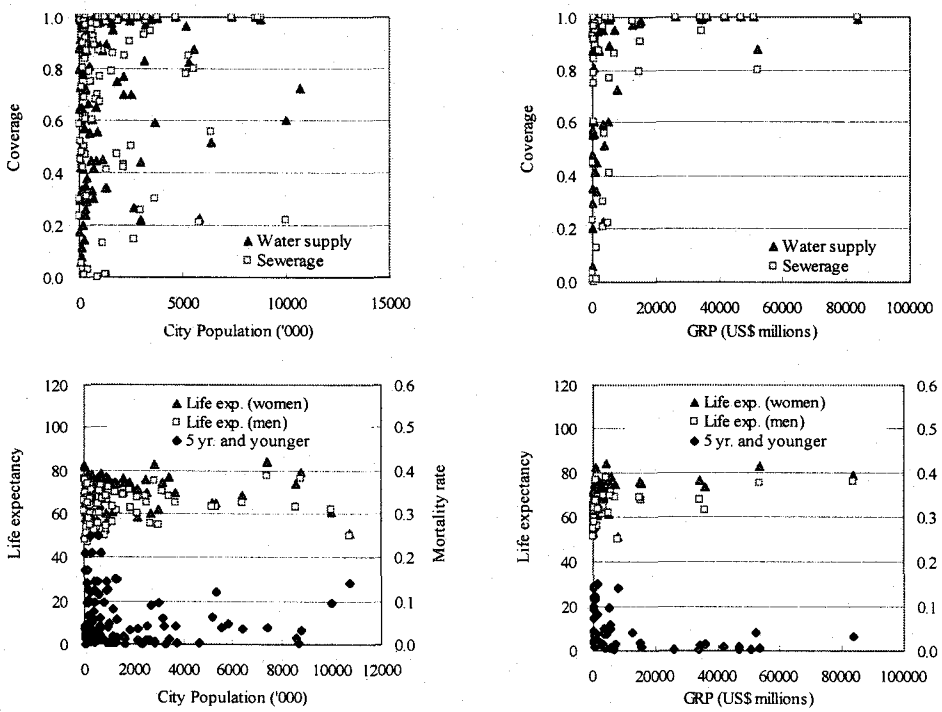


Figure 2a. The relationship between city size and socio-economic and environmental aspects (UN-HABITAT, 2002)

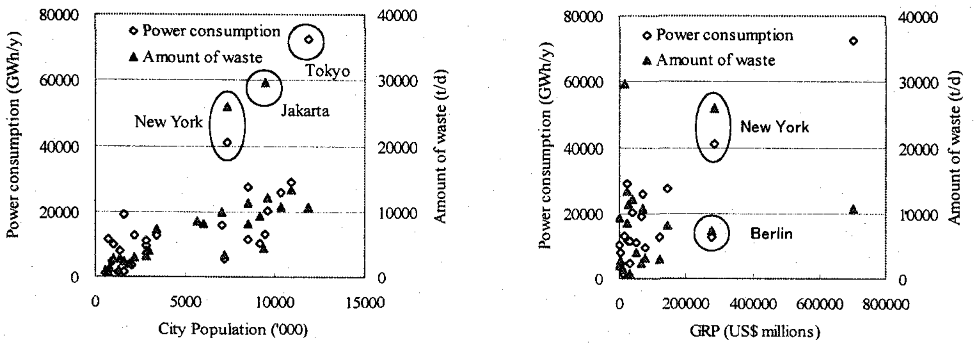
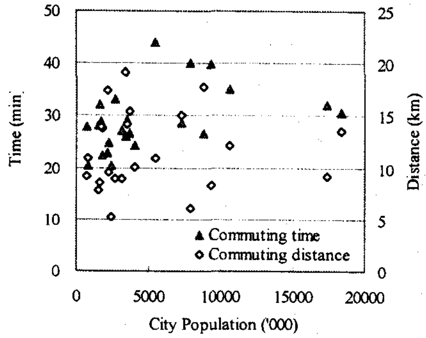


Figure 2b. The relationship between city size and socio-economic and environmental aspects (Secretariat of the Summit Conference of Major Cities of the World, 2000)



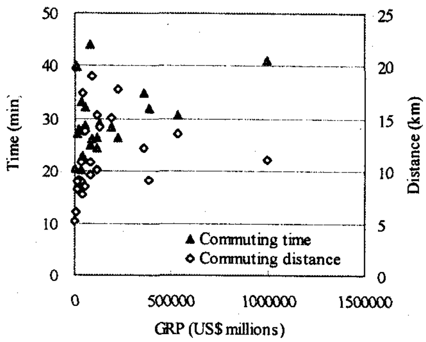


Figure 2c. The relationship between city size and socio-economic and environmental aspects (Jeffrey and Felix, 1999)

(2) The relationship between urban compactness and environment

The results shown in Figure 2 indicate that when assessing a city's environmental quality, it is not sufficient to look only at the city size (population or GRP). We assumed a city's compactness (population, activity, and traffic densities) to be important in assessing environmental impact, so conducted further comparisons.

First, we investigated the relationship between urban density commuting distance and commuting time, as seen in Figure 3. We found that if the population density is less than about 200 people per ha, the commuting distance tends to become shorter as population density grows, but commuting time becomes longer. When the population density exceeds about 200 people per ha, both commuting distance and time tend to increase. The increase in commuting time is explained by the lower average speed that comes with greater use of public transport and longer commuting distances. However, the steady increase in commuting distance when the population exceeds about 200 people per ha may be attributed to such factors as the rising land prices and housing shortages that accompany higher population densities and cause some people to move to the city suburbs. In this way, the city expands.

We also investigated the relationship between population density and traffic exhaust gas emissions. Figure 4 shows the relationship between per capita GRP and population density, and emissions of CO_2, SO_x, NO_x, and CO. CO_2 and SO_x emissions peaked at a per capita GRP of about US$30,000 before declining. The trends for NO_x and CO emissions were not as clear, but they peaked at a per capita GRP in the vicinity of US$25,000 US dollars before declining. This suggests that a city's environmental load decreases as the city develops and matures economically. However, there are limits to the increase in urban density considered necessary for economic development. A look at population density and the amount of pollutants emitted by urban transport shows that emissions tended to decrease up to a population density of 100 people per ha, but gradually increased as populations grew beyond this level. The results shown in Figures 3 and 4 suggest that a certain level of economic growth and population density are necessary to realize a comfortable atmospheric environment and traffic conditions, but that an excessive concentration of people produces an increasing environmental burden.

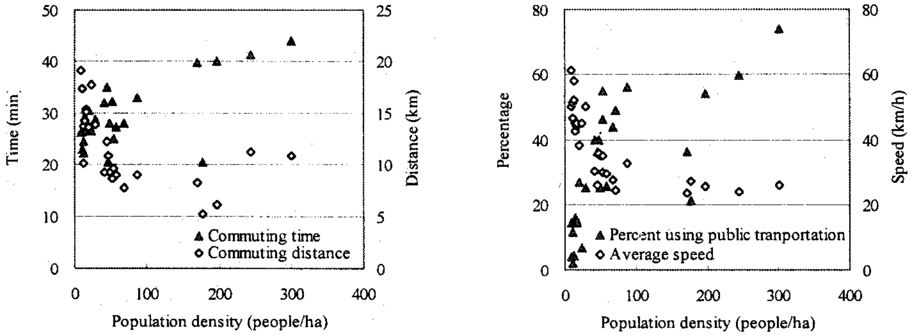


Figure 3. The relationships between population density and commuting time, commuting distance, automobile use and average commuting speed (Jeffrey and Felix, 1999)

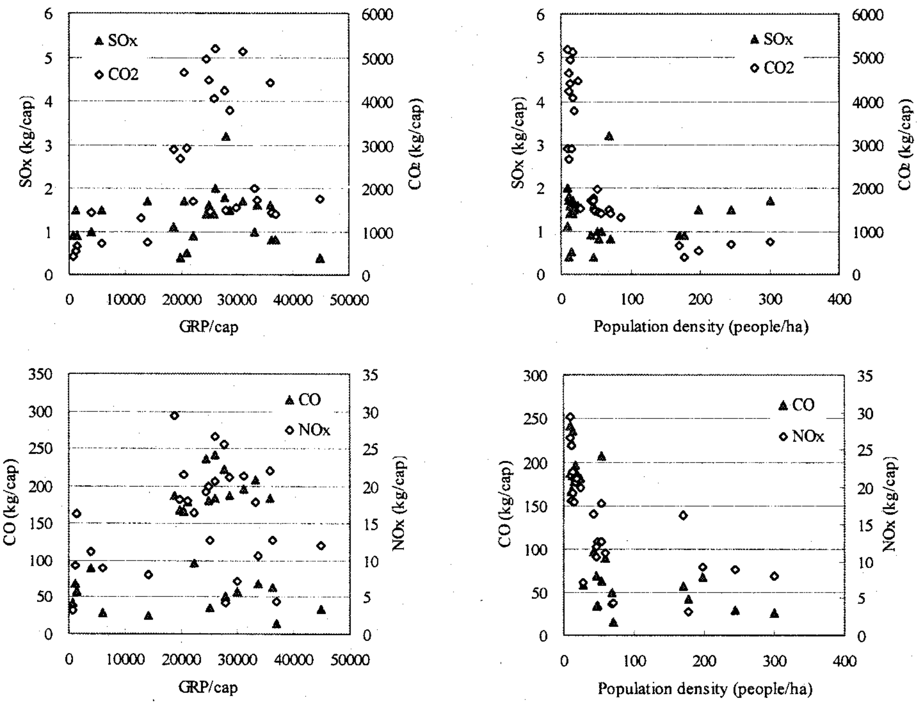


Figure 4. The relationship between urban density and the amount of contaminants released by urban transportation (Jeffrey and Felix, 1999)

3.2 An assessment of spatial changes in population density and urban form

An understanding of a city's concentration (population, economic activity, etc.) and historical trends is needed to determine the potential for developing sustainable compact cities. The national census in Japan identifies densely inhabited districts (DIDs), and uses these districts to count the population. To investigate the differences in urban form and population density between developing and developed countries, in the present study we used the ISADC city structure. It comprises the following zones: Outer City (the entire city out to the boundary zone of the Outer Area - includes the Inner City and Central Business District (CBD)); Inner City (the city center out to the Inner Area boundary zone - includes the CBD); and the Central Business District (CBD - center of the city's activities). Assuming that the area of each urban region is a circle, each area is expressed as the diameter of that circle, and then expressed by plotting with the diameter against population density, as in Figure 5.

For example in Australian cities, on average the Outer City grew larger each year until 1990, when the population density was 10–20 people per ha in the Outer City, 19–39 people per ha in the Inner City, and 10–21 people per ha in the CBD. These densities are typical of automobile-oriented cities, commonly seen in developed countries. Similar historical trends for spatial change were seen in the United States, with the exception of San Francisco and the huge metropolis of New York. In Europe, despite declining annual population densities, the average population densities in 1990 were about 29–75 people per ha in the Outer City, 54–180 people per ha in the Inner City, and 50–180 people per ha in the CBD. Thus, European cities still maintain high population densities compared with Australia and the United States. The spread of the Outer City is also smaller than that in Australia or the USA, so there is no dramatic change in city size or population. In Asia, on the other hand, the developing cities of Kuala Lumpur and Manila expanded. The developed cities of Singapore, Tokyo, and Hong Kong showed very high population densities, but their densities are gradually decreasing. The cities examined here show clear time-related trends in form and population density, indicating the need for planned development to create compact cities.

3.3 Environmental assessment using ecological footprints

As shown in Figures 2 to 5, we used various indicators to assess cities from the macro viewpoint. However, since all cities do not necessarily maintain the same databases, making comparisons between cities is problematic. Therefore, to be able to make comparative assessments of the sustainability of different cities and investigate the effectiveness of compact cities, we applied the ecological footprint (EF) indicator to Japanese municipalities and conducted an analysis of various regions. The EF is an indicator that expresses in units of "area" the various impacts on ecosystems caused by economic activities (Wackernagel and Rees, 1996). The World Wildlife Fund (WWF) has calculated the EF for many countries, which consists of cropland EF, grazing land EF, forest EF, fishing ground EF, energy EF, unproductive land EF.

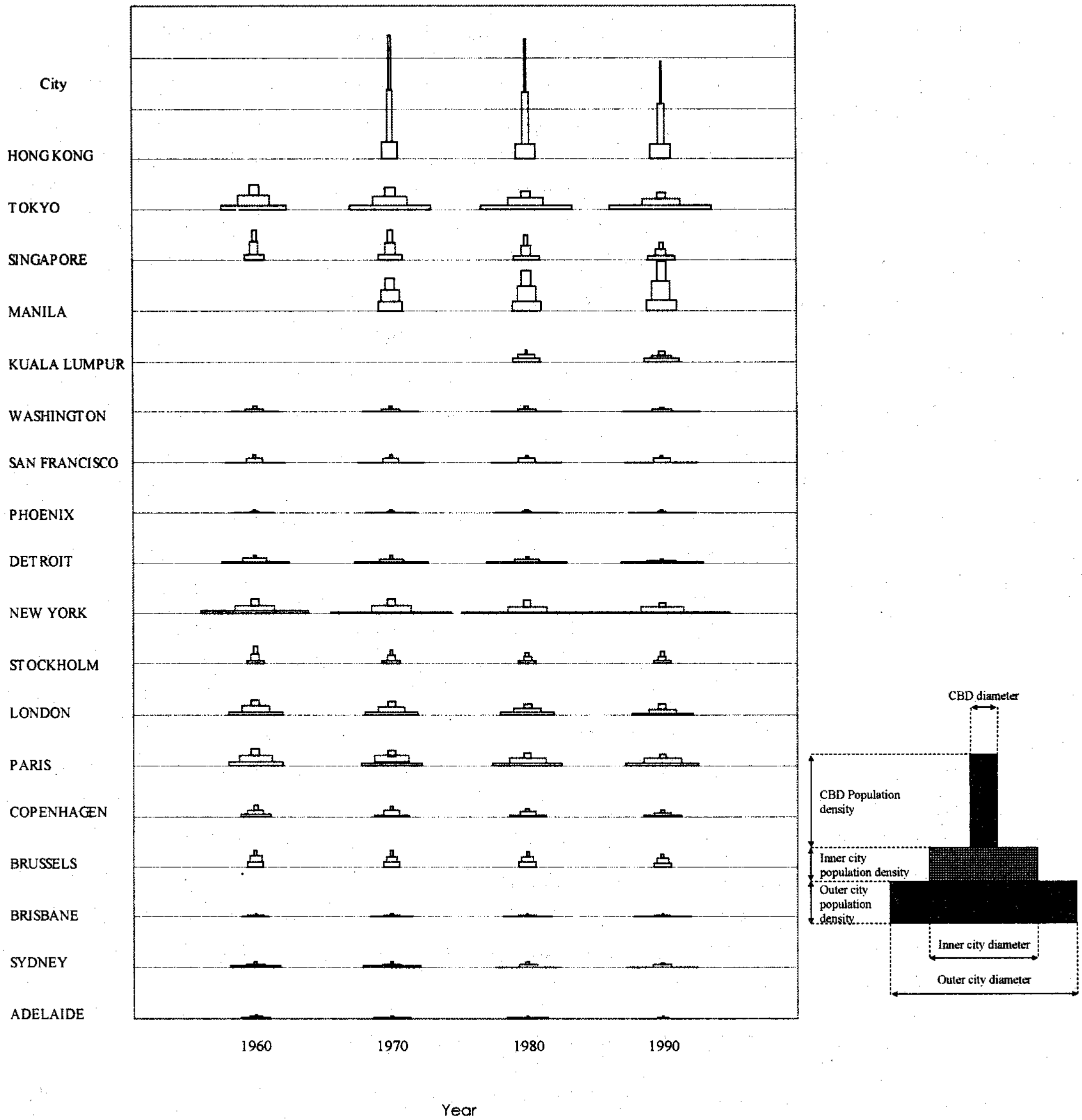


Figure 5. City form and spatial changes in population density

In 1996, Japan had the world's 23rd largest EF of 5.9 ha per person (cropland EF: 0.8 ha per person; grazing land EF: 0.4 ha per person; forest EF: 0.6 ha per person; fishing ground EF: 0.2 ha per person; energy EF: 3.7 ha per person; and manufacturing capacity inhibited land EF: 0.2 ha per person) (WWF, 2002).

Calculating the EF for a nation, region or city requires data on domestic and foreign production and raw material supply for all commodities, plus detailed data on the energy needed for social and economic activities. Obtaining these data also requires massive amounts of time, effort and money. However for this study, we used the EF values for Japan reported by the WWF to estimate EF values for each region based on the following assumptions:

1) EF for food (cropland EF, grazing land EF, fishing ground EF): is expressed as a proportion of income
2) Forest EF: is expressed as by consumer spending on wood products and a proportion of income
3) Energy EF: is expressed as a proportion of total production value and revenue
4) Unproductive land EF: is expressed by the nation's area of roads and residential land.

Data used in preparing the regional EF estimates (income, consumer spending (for wood products), total production value, revenue, roadway area, and residential land area) were obtained from the Statistics Bureau of the Ministry of Public Management, Home Affairs, Posts and Telecommunications (2000) and the Statistics Bureau of the Ministry of Economy, Trade and Industry (1995).

To investigate the effectiveness of compact cities, we examined the relationship between population density and EF values through the total population of cities (100,000–500,000 people, and more than 500,000 people) (Figure 6). The per capita EF, regardless of total population, tended to rise gradually with increasing consumption of food and energy, and population density. Food EF showed a dramatic increase when a city's population density exceeded approximately 100 people per ha, and energy EF was also classified using a delineating point of 100 people per ha into high (more than 100 people per ha) and low (fewer than 100 people per ha) EF groups.

Also, we investigated the relationship between total EF and population size of cities through their population density (less than 50 people per ha, 50–100 people per ha, and more than 100 people per ha). Figure 7 shows that when the total population was more than 500,000, both energy and food EF were larger in cities with a population density of more than 100 people per ha than in cities of the same size but with a lower population density. Conversely, when a city's population was less than 500,000, the rate of increase in EF that accompanied increasing population size showed a nearly two-fold difference between cities with population densities of over 100 or less than 50 people per ha. With population densities of 50–100 people per ha, there was a tendency for cities to have either a low EF (similar to cities with a population density of less than 50 people per ha) or a high EF (similar to cities with a population density of more than 100 people per ha). This was especially true with energy EF.

These results indicate that excessively high city densities may lead to a very high consumption of resources, particularly of food and energy.

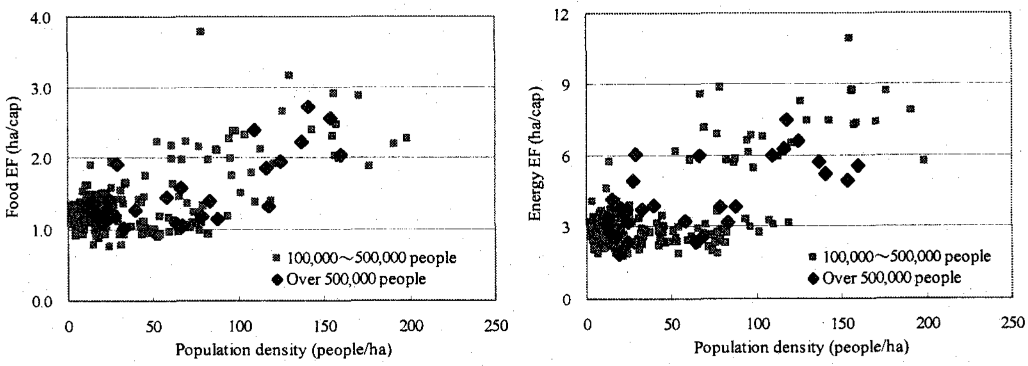


Figure 6. The relationship between EF and population density

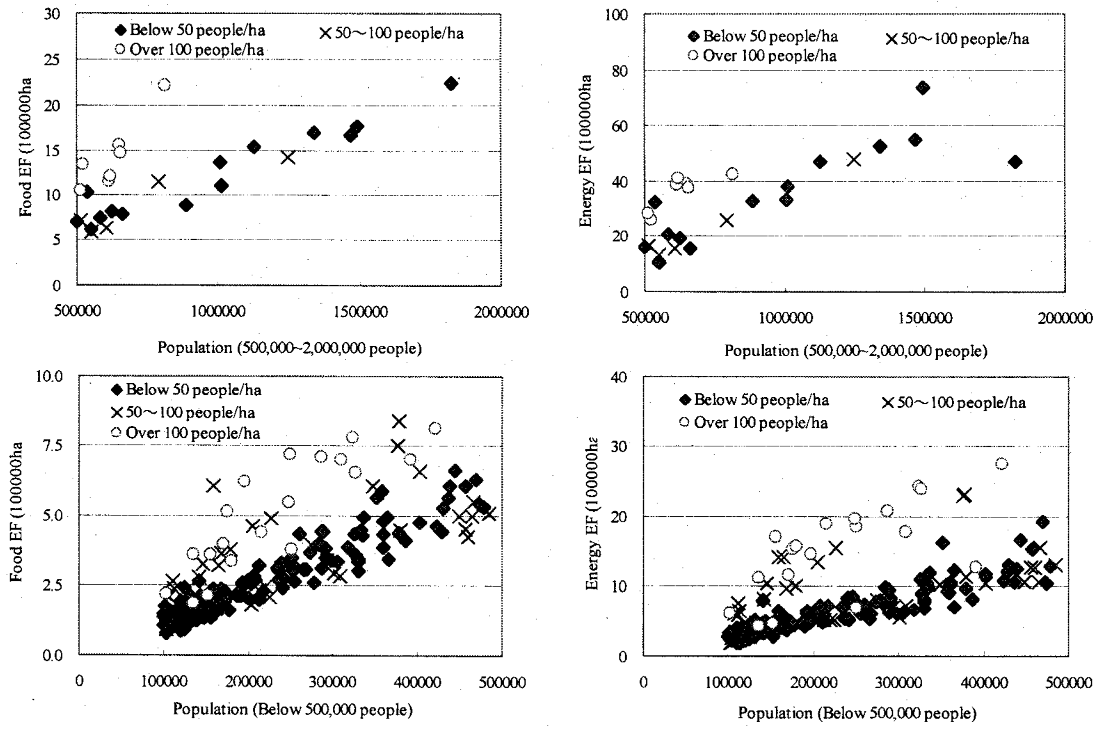


Figure 7. The relationship between EF, population size and population density

3.4 An assessment of the compactness of target cities in Japan

(1) Organizing outcome indicators

When investigating the desired attributes of compact cities, it is necessary to not only examine those urban forms that have a small environmental load because of their function and efficiency, but also to examine how the people in that city live. Thus, even if one builds a purely functional city, it would not meet this study's definition of a compact city—great amenity with a small environmental burden—if the people living there did not have a sense of safety and security, and be both physically and mentally satisfied. Thus, the outcome indicators that serve as aids in achieving the development of a compact city were identified and grouped in relation to urban function, as in Table 3.

(2) Selection of target cities

Using the outcome indicators in Table 3, urban functions of all Japan's municipalities (3,236 in 1996) were assessed and analyzed. This study targeted typical Japanese cities with social capital and living standards above specific levels, and investigated whether urban compactness is effective in realizing a sustainable, environmentally friendly city. We selected target cities using the urban classification of the National Land Agency's Planning and Coordination Bureau that consists of four social capital improvement levels (1996), as in Table 4. Of the urban categories, the "Standard city group" included many typical Japanese cities with a good balance among the various types of social capital. A very high percentage of towns and villages included in the Standard city group did not have of urban functions that reached specified levels, so 2,564 of the 3,236 towns and villages were excluded from the study, and 672 cities were selected as subjects for the analysis. About 90% of 672 cities were included in the "Standard city group."

(3) Establishing indicators for social compactness

In this study, a "walkable city" was regarded as one desirable feature of a compact city. As an outcome indicator, "walkability" in particular was considered to be able to define "social compactness," and this function was assessed quantitatively for each of the 672 cities. The proportion of houses located within 1 km of the nearest public and commercial facilities required for daily life was calculated against the number of all homes using data from Japan's 1998 Residential and Statistical Survey (Statistics Bureau, Management and Coordination Agency, 1998). Here, a distance of less than 1 km to the nearest public and commercial facilities was assumed to be a range that a healthy adult could walk comfortably.

Japanese cities contain many such facilities or services, but for convenience, eight facilities were chosen for this study's assessment of accessibility, and grouped into four categories based on their purpose, as seen in Table 5. Because these categories have a different influence on social compactness, we should put different weights on these categories. However, we gave them equal weights. The following equation expresses the way they influence social compactness:

$$\text{(Social compactness)} = A_1+1/2*(B_1+B_2)+1/4*(C_1+C_2+C_3+C_4)+D_1$$

(4) Assessment of social compactness

To assess the relationship between social compactness and spatial compactness (population density) in a walkable city, the relationship between the eight indicators in Table 5 and population density were compared, as seen in Figure 8. The proportion of people who lived within 1 km of a medical institution, convenience store, post office and bank showed a strong positive correlation with an increase in population density. When the population density exceeded about 50 people per ha, the proportion of people living within 1 km of the nearest medical institution and convenience store was about 80%, while more than 70% were within 1 km of a bank and post office. The proportion of people within 1 km of a park, community center, assembly hall and emergency evacuation site showed more variation than the first three facilities, but even so a clear trend was seen for this proportion to increase with increases in population density. The proportion of people within 1 km of the nearest transportation facility (station) showed a gradual increase with increases in population density, but there was much variation. This is due to the way the different topography and policies of each city influence the development of local transport facilities. The proportion of people living within 1 km of the nearest senior citizen day care center showed almost no increase as population density increased. Because such centers are visited by a limited number of people, they do not have to be in optimum locations for all residents.

Table 3. Outcome indicators for achieving a compact city

Basic objectives of urban policies	Urban policy indicators		Indicators for achieving a compact city
Mechanisms to protect lives and livelihood		Full crisis management in disaster emergencies	Number of building fires/number of households Distance to nearest emergency evacuation site Number of known crimes/Total population
	Living Environment	Safe, unpolluted living environment Social infrastructure that does not burden the global environment	Number of pollution complaints/Total population
	Traffic safety	Road transportation facilities that anyone can use safely Traffic control by IT	Number of traffic accidents/Total population
Security Support mechanisms for a healthy and secure lifestyle	Public health	Living foundation for hygienic and healthy living	Waste disposal population/Total population Human waste treatment population/Total population Amount of treated waste/amount of waste collected annually Coverage of public water and sewage lines
	Housing	Construction of housing stock Building walkable cities	Number of households/Total area New housing starts/Total area
	Medicine & welfare	Easy access to medical and welfare facilities Enhanced town planning for towns that are easy to live in	Number of general hospitals and clinics/Total population Distance to nearest medical facility Number of senior citizens homes/Total population Distance to nearest senior citizens day service center Number of nursery schools/Total population
	Education	Enhancement of lifelong learning & environmental learning	Number of kindergartens/Total population Number of elementary schools/Total population Number of middle schools/Total population Number of high schools/Total population
	Industrial development	Industrial base to support the regional economy	Crude agricultural production/Total population Value of shipped manufactured goods/Total population Annual sales total/Total population
Convenience & comfort Support mechanisms for convenient and comfortable daily life	Urban facilities	Enhancement of community centers, libraries, day care centers Enhancement of parks and station squares Convenience of community roads	Number of community centers/Total population Distance to nearest community center, assembly hall Number of libraries/Total population Number of city parks/Total population City park area/Total population Distance to nearest park Number of post offices/Total population Distance to nearest post office and bank Distance to nearest convenience store Total road length/Total area
	Transportation	Convenience and comfort of regional trunk lines Convenience of local transportation facilities	Degree of use of public transportation for commuting to work and school Distance to nearest transportation facility (station) Number of automobiles owned
Beauty & leisure Mechanisms to provide a beautiful and leisurely lifestyle	Natural environment	Build a country that retains large areas of pristine natural areas Protect and preserve precious plants and animals Preservation of local green areas	Habitable area/Total area DID population/Total population
	History & culture	Preservation of historical resources Create beautiful cityscapes Communication among people	Number of national treasures, important cultural assets/Total population Number of visitors/Total population

Table 4. City classifications

Social capital improvement levels (4 classes) Classifications based on the relationship between quantitative amount of infrastructure in municipalities and the balance of facilities to infrastructure	Standard city group	Approximately 2000 municipalities were classified in the standard city group in Japan. Considered to be in the final stages of social capital improvement
	Spacious urban area city group	Strong special trends in per capita parkland area and proportion of public housing
	Facilities specialization city group	Pavement ratio, waste collection rate, coverage of water and sewer lines, and other such facilities that are installed in stages are not yet mature, but the level of facilities such as community centers, museums, and nursing homes for the elderly that are not developed stepwise shows a strong special trend
	Lack of sanitation facilities city group	Low pavement ratio, waste collection rate, coverage of water and sewer lines, and other facilities, especially those related to sanitation

Table 5. Indicators of social compactness based on 'walkability'

Basic desires for cities	Nearest public and commercial facilities group
Safety	Emergency evacuation site (A_1)
Security	Medical facilities (B_1), senior citizens day care center (B_2)
Convenience	Community center/assembly hall (C_1), post office/bank (C_2), convenience store (C_3), transportation facility (station) (C_4)
Beauty, leisure	Park (D_1)

Thus, most of the items chosen to reflect urban social compactness showed a positive correlation with population density, indicating the need for higher spatial density to improve social compactness. However, some items such as transportation facility (stations) or senior citizens centers were not affected by spatial compactness. This demonstrates the need for the planned distribution and spread of urban functions to achieve a compact city.

(5) Assessments using multiple indicators

We investigated the relationship of population density to the economy and environment. Figure 9 shows the relationship between the economy (per capita taxable income - hereinafter income) and the environment (per capita production of waste - hereinafter waste production). First, looking at the relationship between income and waste production, we see that when a person's income exceeds approximately 1.8 million yen per year, waste production converges to 0.2–0.5 tonnes per person per year. However, waste production does not uniformly decrease as income increases. When income exceeds 2.0 million yen per year, waste production also increases to about 0.4 tonnes per year. This decline in waste production with income to a certain level, followed by a gradual increase as income rises, is thought to be caused by an increased consumption of resources from the improved quality of life that accompanies economic growth, even though cities also become more advanced and use resources more efficiently.

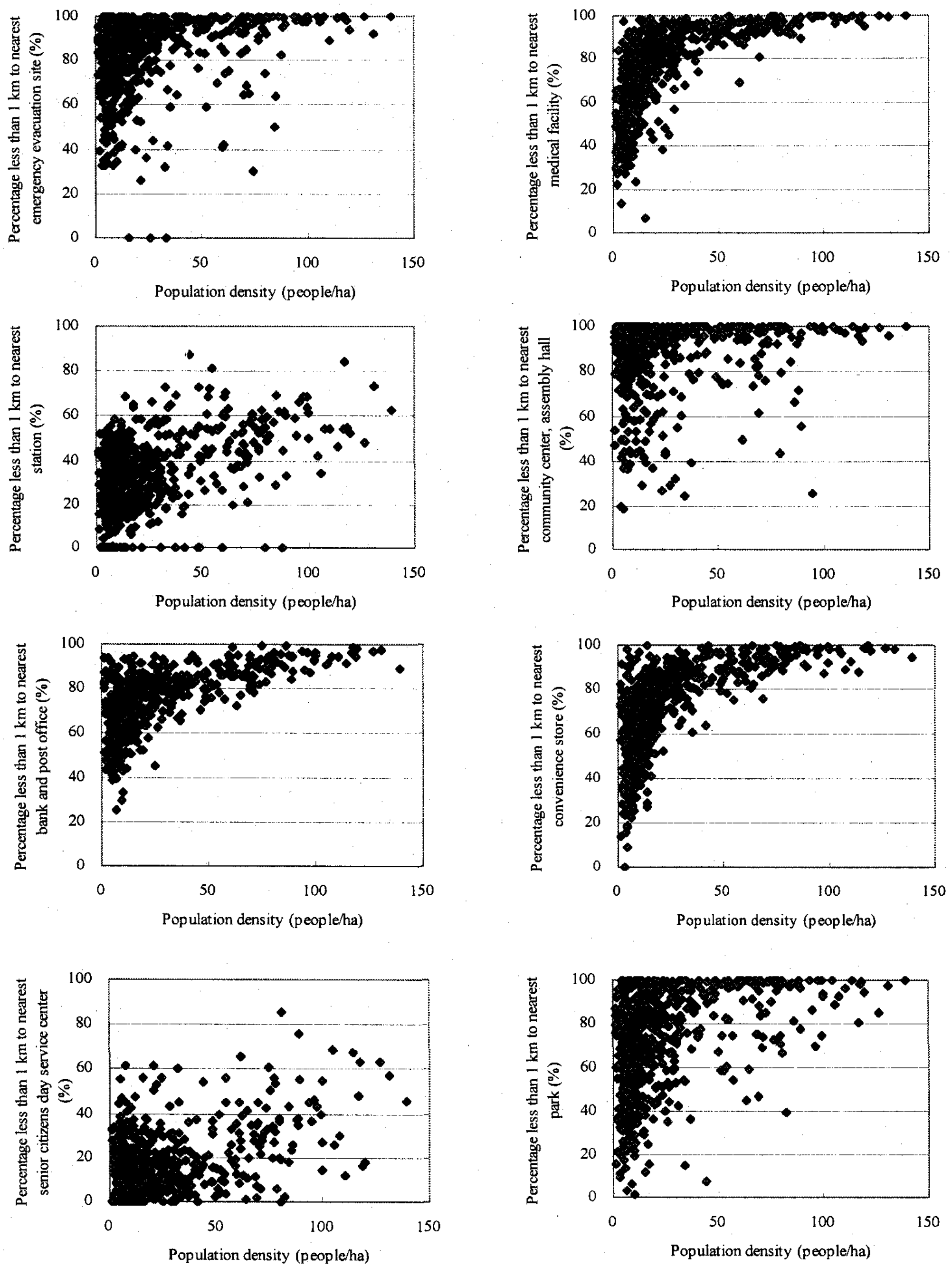


Figure 8. The relationship between population density and social compactness

An examination of the relationship between waste production and income by population density shows that in cities with a population density of less than 50 people per ha, income varies from 720,000 to 2.4 million yen per year, but it is concentrated at lower levels. Waste production also varies widely from 0.19 to 0.94 tonnes per year, exceeding 0.6 tones per year in 21 cities. In cities with population densities of 50–100 people per ha, income is concentrated at higher levels of 2.0 million yen per year. There is little variation in waste production, which is between 0.4 and 0.54 tonnes per year and concentrated at about 0.4 tonnes per year. Cities with population densities of over 100 people per ha showed almost no difference to cities with population densities of 50–100 people per ha.

Thus, up to a certain level, population density increases with economic growth, while waste production declines. However, after economic activity and population density reach a certain level, waste production begins to increase, suggesting that there is a limit to the benefits of improving spatial compactness.

(6) Assessment by grouping

We also investigated the relationship of spatial compactness to the economy, environment, and society. Since it was very difficult to simultaneously compare multiple indicators for the 672 target cities, these cities were categorized into 6 classes by population density (G1: fewer than 25 people per ha; G2: 25–50 people per ha; G3: 50–75 people per ha; G4: 75–100 people per ha; G5: 100–110 people per ha; and G6: more than 110 people per ha). These six classes were compared for their trends in income, waste production, and social compactness, as in Figure 10. Here, 'social compactness' is an indicator that integrates the eight items shown in Table 5.

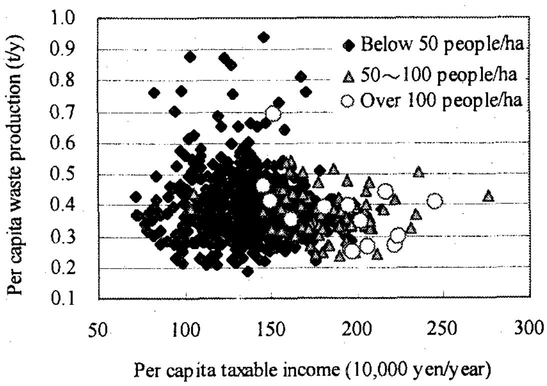


Figure 9. The relationship between the economy and the environment expressed through population density

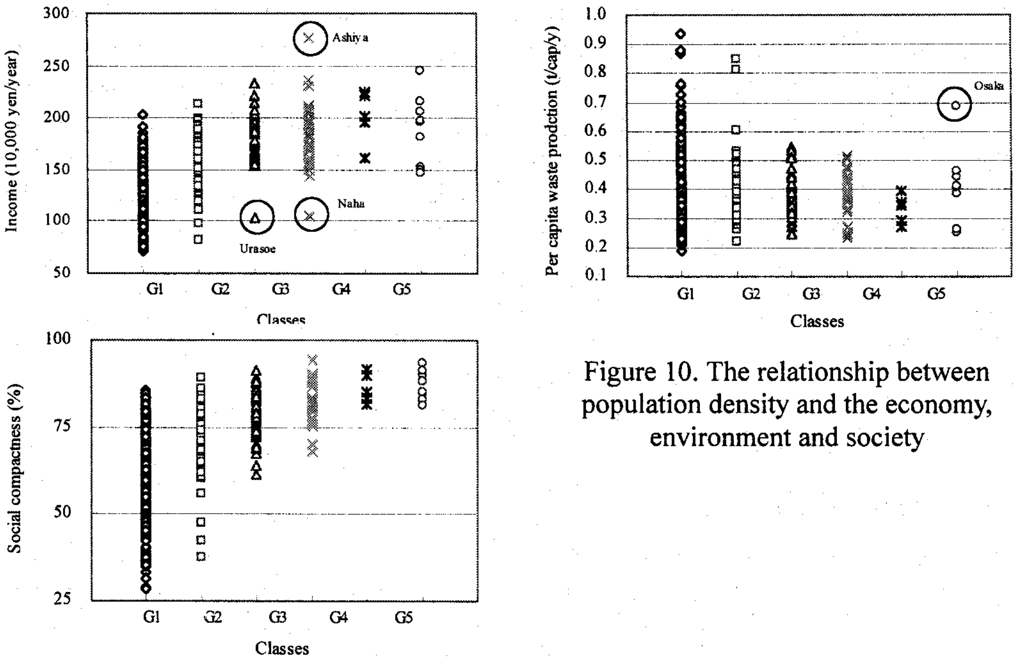


Figure 10. The relationship between population density and the economy, environment and society

In the low population density groups, G1 and G2, income is low. While there are some cities with low waste production, the maximum values reach 0.94 and 0.85 tonnes per year. There is also variation within social compactness despite the low values shown. Income is higher in G1 than in G2, and while there are cases in which waste production decreases and social compactness increases compared with G3–G6, income and social compactness are especially low, being similar to cities in developing countries. Compared with G3–G6, almost the same values are seen for income, with the exceptions of Urasoe City (1.03 million yen per year), Naha City (1.06 million yen per year), and Ashiya City (2.77 million yen per year). G5 has the lowest maximum value for waste production (0.39 tonnes per year), and in G6, which has the highest population density, a trend is seen for higher waste production than in G5 even with the exclusion from G6 of Osaka, which has a very high level of 0.69 tonnes per year. In terms of social compactness, all G3–G6 municipalities exceeded 90% of the highest value, with the variation in G5 and G6 being nearly the same. As with waste production, there seem to be limits to the effects of increasing spatial compactness.

This comparison of the six classes indicates that cities with more than 50 people per ha could have a high probability of becoming a compact city - one with high spatial and functional densities, low environmental loads and maximum amenity. However, it also seems that excessive economic growth or high population densities will be obstacles to the creation of sustainable compact cities.

4. Conclusion

To explore ways of developing sustainable cities, we presented a framework for making urban assessments that incorporates consideration of the environment, society, economy, and compactness. Using a database of cities and their characteristics, we conducted an urban environmental assessment by applying various indicators centered around population density.

Our assessments produced the following results:

1) The city environmental assessment using macro-indicators illustrated the need for specific levels of economic activity and population densities to achieve a comfortable living environment. However, when the population density exceeds about 200 people/ha, both commuting distance and commuting time tend to increase. Also, the transport emissions tend to decline up to a population density of 100 people per ha, but gradually increase as populations grow beyond 100 people per ha. These results suggest that excessive concentrations of people may lead to an increased environmental load.
2) The investigation of urban form and population density in developing and developed countries showed clear annual changes in form and population density, indicating the need for planned development to create compact cities.
3) The comparative assessment of sustainability among cites using the EF indicators showed that excessively high population densities in cities may lead to a high level of resource use.
4) The integrated assessment of population density, economy, environment and social compactness indicated that, up to a certain level, population density increases with economic growth, while waste production declines and social compactness increases. However, after economic activity and population density reach a certain level, waste production begins to increase while social compactness becomes constant, suggesting that there is a limit to the benefits from increasing spatial compactness. This indicates that an appropriate spatial compactness is needed when creating a compact city.

Previous research discussed the concept of a compact city, but our research provides concrete features on which to base such a city. The next steps in advancing the comprehensive evaluation of suitable urban forms for achieving sustainable compact cities should be: 1) develop a more detailed city database; 2) conduct parallel investigations of cities using a greater variety of indicators; 3) analyze the internal structure of cities in more detail; and 4) prepare quantitative goals to be achieved by sustainable compact cities.

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