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A GIS-BASED ANALYSIS OF JOBS, WORKERS, AND JOB ACCESS IN TOKYO

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Abstract
Understanding urban spatial structures is essential to develop effective planning. This study presents a GIS-based analysis of Tokyo's urban spatial structure by examining spatial distributions of jobs, workers, and job access by travel mode. The study shows Tokyo's distinctive monocentric structure with highly centralized jobs and workers. Jobs are, however, far more centralized than are workers. The computed job-access measures indicate that job accessibility is markedly higher in central-city areas, particularly around CBDs, than in suburban areas. The measures also indicate that although Tokyo offers well-developed transit systems, job accessibility is considerably lower for transit commuters than for auto commuters. Several future directions of this research are discussed.

1. Introduction

As more and more urban areas exhibit sprawling and auto-dependent urban structures, planning tools that encourage compact development and non-auto travel options have drawn considerable attention worldwide in recent years (e.g., Kaidou 2001; Kenworthy *et al*. 1999; Newman and Kenworthy 1999). Examples are Smart Growth and Transit-Oriented Development (TOD), which aim to mitigate undesirable consequences of sprawl and to promote livable, accessible, and sustainable urban development (e.g., Benfield *et al.* 1999; Bernick and Cervero 1997; Boarnet and Chompin 1999; Koizumi and Nishiura 2003).

Understanding urban spatial structures is essential to develop effective planning. Examining urban structure from a perspective of job access for U.S. metropolitan areas, Kawabata (2002) and Shen (1998, 2001) find that job accessibility is much lower for transit commuters than for auto commuters and that the mode of travel has greater importance in determining job accessibility than location. This paper extends their research by examining spatial distributions of jobs, workers, and job access for the Tokyo metropolitan area.

Specifically, this study asks the following two research questions: (1) what are the geographies of jobs and workers in Tokyo? and (2) to what extent does the level of job accessibility vary by location and travel mode?

The urban spatial structure differs between Tokyo and U.S. areas. While many U.S. metropolitan areas have decentralized and auto-oriented development patterns, Tokyo is well known for its highly centralized employment and well-developed public transit systems. It is expected that for Tokyo, job accessibility is much higher in central-city areas than in suburban areas while a difference in job accessibility between auto and transit users is not that great.

Geographic Information Systems (GIS) are used to visualize the spatial patterns of jobs, workers, and job access in three dimensions (3D). To show spatially disaggregated pictures of distributions with great variability, 3D visualization is particularly beneficial. The examination of those spatial patterns gives a perspective of Tokyo's urban spatial structures.

This paper is organized as follows. Section 2 describes the methodological framework, and Section 3 presents empirical findings. In Section 4, the findings are summarized with a discussion of future research directions.

2. Methodology

2.1 Data and Study Areas

Data on jobs and workers are from the 2000 Population Census of Japan. Workers are defined as persons 15 years of age and over who are in the labor force. The census data provide information on the number of employed workers by area of work, which are used as job count. Data on origin-to-destination (OD) average travel time are from the 1998 person trip survey conducted by the Tokyo Metropolitan Region Transport Planning Commission (TMRTPC). The survey includes approximately 883,000 respondents who reside in the Tokyo metropolitan area. The survey data are not publicly available but minimum data necessary for a study with the purpose of urban and transportation planning can be borrowed from the Institute of Behavioral Sciences (IBS). The OD travel time borrowed from IBS for this research includes waiting time and is computed for peak hour (arrival time between 7:00AM and 9:30AM) for auto commuters and for transit commuters.

The study area is the Tokyo metropolitan area, which is depicted in Figure 1. There are several ways to delineate the Tokyo metropolitan area. The study area for this research is consistent with the Tokyo metropolitan region defined for the 1998 person trip survey, which covers Tokyo, Kanagawa, Saitama, and Chiba prefectures, and a southern section of Ibaragi prefecture. Figure 1 also shows the 23-ku area, which consists of 23 wards in Tokyo, and the 3-ku area, which has three wards (Chiyoda-ku, Chuo-ku, and Minato-ku). In this study, the 23-ku area is considered the central city, and the 3-ku area the Central Business Districts (CBDs). The geographic unit of the analysis is the basic planning zone delineated specially for the person trip survey. The Tokyo metropolitan region for the 1998 person trip survey contains 595 basic planning zones. Since census data are not available for this zone, I use GIS to create an area-weighted factor table and convert city-level census data to the data by basic planning zone.

< Figure 1 >

Table 1 shows basic population and transportation characteristics of the Tokyo metropolitan area. To better understand specific characteristics of Tokyo, Table 1 also reports the characteristics for the U.S. nation and two U.S. metropolitan areas, Boston and Los Angeles. The land area of the Tokyo metropolitan area (the study area shown in Figure 1) is 3,766 square miles, which is roughly the size of Los Angeles PMSA (Los Angeles County). The land area for Tokyo's central city (the 23-ku area) is 211 square miles, which is about four times that of the city of Boston and roughly half of that of the city of Los Angeles. Tokyo has exceedingly large population, accommodating approximately 35 million metropolitan people.

Tokyo is much less auto dependent than is the U.S. In the Tokyo metropolitan area, the proportion of households without autos is 43%, much higher than 10% for the U.S., and the proportion of workers who use autos to get to work is 32%, which is considerably lower than 88% for the U.S. Instead, people in Tokyo are more likely to use public transportation than to use autos, having 48% transit commuters. The auto use in Tokyo, however, has been increasing overtime. Between 1988 and 1998, the proportion of workers who commute by auto rose from 29% to 32%.

Commuting in Tokyo is notoriously long. The average travel time is 43 minutes, which is 17 minutes longer than the U.S. average of 26 minutes. Travel time for suburb-to-central city commuting, the dominant commuting flow, is particularly lengthy. For this commuting flow, the average commuting time is 56 minutes, and the proportion of workers whose commuting time is 90 minutes or longer is 16% and is *increasing* (TMRTPC 1999).

Table 1 Population and transportation characteristics of Tokyo, compared with U.S. areas

	Tokyo		U.S. Total	Boston		Los Angeles	
	Tokyo metro (study area)	23-ku area (central city)		PMSA	Boston city	PMSA	L. A. city
Land area (sq. mile)	3,766	211	3,537,438	2,022	48	4,061	469
Population	34,860,306	8,092,268 1)	281,421,906 3)	3,398,051	589,141 3)	9,519,338	3,694,834 3)
Workers (persons in the labor force)	18,559,044	4,456,093 1)	138,820,935 3)	1,821,120	308,395 3)	4,312,264	1,690,316 3)
Household without auto	43	68 2)	10 3)	15	35 3)	13	17 3)
Means of transportation to work (%)							
Auto	32	- 2)	88 3)	76	51 3)	86	80 3)
Public transportation (incl. taxicab)	48	- 2)	5 3)	14	32 3)	7	10 3)
Walked	7	- 2)	3 3)	5	13 3)	3	4 3)
Other means	13	- 2)	1 3)	1	2 3)	2	2 3)
Worked at home	-	-	3 3)	3	2 3)	4	4 3)
Mean travel-time work	43	- 2)	26 3)	29	29 3)	29	30 3)
Drive alone	28	37 2)	24 4)	-	-	-	-
Public transportation (incl. taxicab)	60	56 2)*	48 4)	-	-	-	-

Data source : 1) 2000 Population Census of Japan, 2) 1998 Tokyo person trip data, 2)* 1998 Tokyo person trip data, rail, 3) U.S. Census 2000, 4) Census Transportation Planning Package 2000.

2.2 Measurement of Job Accessibility

The calculation of job accessibility is based on Shen's (1998, 2001) formulas that incorporate both the supply and demand of the labor market and the mode of transportation. This study’s job-access formulas are given by:

$$A_i^{auto} = \sum_j \frac{E_{j(t)} \times f(C_{ij}^{auto})}{\sum_k \{\alpha_k W_{k(t)} \times f(C_{kj}^{auto}) + (1-\alpha_k) W_{k(t)} \times f(C_{kj}^{pub})\}}, \qquad (1)$$

$$A_i^{pub} = \sum_j \frac{E_{j(t)} \times f(C_{ij}^{pub})}{\sum_k \{\alpha_k E_{k(t)} \times f(C_{kj}^{auto}) + (1-\alpha_k) E_{k(t)} \times f(C_{kj}^{pub})\}}. \qquad (2)$$

A_i^{auto} and A_i^{pub} are job-access measures for workers living in zone i who are auto commuters and public transit commuters, respectively. $E_{j(t)}$ represents the number of jobs in zone j at time t, and $W_{k(t)}$ indicates the number of workers living in zone k at time t. Impedance functions for commuters traveling between zone i and zone j for auto users and for transit users are $f(C_{ij}^{auto})$ and $f(C_{ij}^{pub})$, respectively. Likewise, $f(C_{kj}^{auto})$ and $f(C_{kj}^{pub})$ are impedance functions for auto commuters and transit commuters, respectively, traveling between zone *k* and zone *j*. The proportion of commuters who use autos in zone *k* is expressed by α_k.[1]

Equations (1) and (2) provide job-access measures that are more representative than the simple ratio of jobs to workers in a given zone, since the foregoing equations incorporate not only opportunities within an area of residence but also opportunities in zones beyond that area, with accessibility values depending on travel costs and travel modes. Each accessibility value is then interpreted as the number of spatially accessible jobs per worker in a given zone.

The geographic unit (zone) is the basic planning zone. The impedance function ($f(C_{ij})$) is specified using two forms. The first form is the simple travel-time threshold function. The value in the impedance function is set equal to one when travel time between zone *i* and zone *j* is less than a threshold travel time; otherwise the value is zero. To examine whether the measures are sensitive to the threshold time, three different thresholds of 15, 30, and 45 minute are used for the job-access calculation. The second form is the impedance estimated using the gravity model. The estimation method is described in Appendix, where gamma (γ) is the parameter used for the travel impedance function.

2.3 Presenting Spatial Distributions of Jobs, Workers, and Job Access

Section 3.1 presents spatial distributions of jobs, workers, and jobs-to-workers ratios, and Section 3.2 shows distributions of the calculated job-access measures. In each of these two sections, I first provide tabulated statistics to show a overall picture of the spatial distributions. With the simple tabulation, however, it is difficult to understand a spatially disaggregated picture of spatial variations. Geographic Information Systems (GIS) are then used to create maps visualizing the spatial patterns of jobs, workers, and job access. Because some areas have extremely high concentrations, the maps are presented in 3D, which can reveal the great variability.

3. Findings

3.1 Spatial Distributions of Jobs and Workers

Table 2 shows workers, jobs, and jobs-to-workers ratios for the entire Tokyo metropolitan area, central city (the area within 23-ku), and suburbs (the area outside 23-ku). As expected, jobs are more centralized than are workers. The proportion of jobs that are located within the central city is 39%, while the proportion of workers who reside in the central city is 24%. This result is reflected in the ratios of jobs to workers. The ratio within 23-ku is greater than one, 1.54, indicating that the central city has more

[1] For the sake of simplicity, in equations (1) and (2), the impedance function for transit commuters is used for all non-auto commuters including those who walk to work. Note that in Shen's (2001) study, α_k is given by the auto-ownership rate in zone *k*; this information is not provided by the publicly available Population Census of Japan.

jobs than workers. The ratio outside 23-ku, on the other hand, is 0.75, about half of that within 23-ku, suggesting that the suburbs contain more workers than jobs.

Table 2 Spatial distributions of workers and jobs in Tokyo

	Entire metro (study area)	Within 23-ku (central city)		Outside 23-ku (suburbs)	
Jobs	16,662,000	6,517,000	(39%)	10,145,000	(61%)
Workers	17,818,000	4,243,000	(24%)	13,575,000	(76%)
Jobs-to-workers ratio	0.94	1.54		0.75	

Note: Workers include both employed and unemployed workers.

Figure 2 shows 3D maps for the densities of jobs and workers and the ratios of jobs to workers, where the length of an elevated feature represents the density or ratio in each zone. To make the maps comparable, legends for the upper two maps (the densities of jobs and workers) use the same equal interval classification, and the z value used to extrude features is made consistent for these two maps.

< Figure 2 >

The maps show clearly Tokyo's distinctive monocentric urban structure. Jobs are heavily concentrated around the central part of Tokyo. Workers are also concentrated around the city center but are much less centralized than are jobs. The map for the jobs-to-workers ratios further indicates the prominent urban core with extremely high ratios around CBDs (Chiyoda-ku, Chuo-ku, and Minato-ku) and inner wards of the central city (e.g., Shinjuku-ku and Shibuya-ku). Some suburban areas (e.g., Nishi-ku and Naka-ku in Yokohama City) have relatively high ratios but those ratios are much less conspicuous than those around CBDs.

3.2 Spatial Distributions of Job Access by Travel Mode

Table 3 presents median values of the job-access measures by travel mode and by location. The access measures are presented for the different impedance specifications, the specification using travel-time thresholds of 15, 30, and 45 minutes and the specification using gamma calibrated from the gravity model. The median values, instead of the average values, are used since the access measures' distributions are considerably skewed.

Table 3 Median job-access measures in Tokyo

	15-min threshold			30-min threshold			45-min threshold			gamma		
	Entire metro	Within 23-ku	Outside 23-ku	Entire metro	Within 23-ku	Outside 23-ku	Entire metro	Within 23-ku	Outside 23-ku	Entire metro	Within 23-ku	Outside 23-ku
Transit	0.65	0.86	0.62	0.34	1.15	0.30	0.48	1.76	0.41	0.66	0.78	0.64
Auto	1.14	2.24	1.03	1.92	4.48	1.69	1.44	2.51	1.35	0.88	1.38	0.85

The absolute values of the access measures are highly sensitive to the impedance specifications. In all specifications, however, consistent patterns are observed. Job accessibility is consistently higher in the central city than in the suburbs, as expected from the highly centralized employment. For example, suppose that workers commute up to 30 minutes. If a typical transit commuter lives in a typical suburban zone, he or she has an access measure of only 0.30 jobs per worker, but if the same transit commuter lives in a typical zone in the central city, such a commuter has an access measure of 1.15 jobs per worker.

A large discrepancy between transit and auto users is also discerned. Job accessibility for transit users is consistently much lower than that of auto users, which is an unexpected result since Tokyo provides well-developed transit systems. Suppose that maximum travel time to work is 30 minutes. While a typical transit commuter in a typical zone in the central city has an access measure of 1.15 jobs per worker, a typical auto commuter in that zone has an access measure of 4.48 jobs per worker.

The central city versus suburban dichotomy in the above table provides rather aggregated pictures of job accessibility. To show more geographically disaggregated pictures, Figures 3a-d present 3D visualizations of job-access measures. Figures 3a, 3b, and 3c show the job-access measures calculated using the travel time thresholds of 15, 30, and 45 minute, respectively, and Figure 3d displays the measures computed using gamma calibrated from the gravity model. For comparison, all maps in these four figures use the same equal interval classification, and the z value to extrude features in two maps in each figure is set to be equal.

< Figure 3a >
< Figure 3b >
< Figure 3c >
< Figure 3d >

Although the spatial variation in job accessibility differs across the different impedance specifications, similar patterns are found. With the 3D maps, it is apparent that areas around CBDs have considerably higher job accessibility than do suburban areas. Some suburban zones (e.g., Nishi-ku and Naka-ku in Yokohama City) have high job-access levels, but still, those levels are not comparable to exceedingly high job accessibility around the central zones.

The maps also show a great transit/auto disparity. In all impedance specifications, job accessibility is much higher for auto commuters than for transit commuters. For auto commuters, most areas have job-access measures greater than one, whereas for transit commuters, many suburban areas have access measures less than one, and areas with high job accessibility are largely limited to the central zones.

It is interesting to find that some so-called *suburban centers* have high job accessibility for auto users but low accessibility for transit users, suggesting high auto dependency in those areas. For example, when job accessibility is calculated with the 45-minute threshold, some suburban zones in Machida-shi, Hodogaya-ku, Hachioji, and Tsuzuki-ku have auto accessibility greater than 2.0 but transit accessibility less than 0.5. These suburban centers provide developed rail and bus systems, but neighborhoods' auto ownership rates are high and people tend to use autos for traveling in and around the suburban centers.

It is also interesting to see that some zones in the outer suburbs have relatively high job accessibility, particularly for auto commuters. These areas include some southernmost zones in Chiba prefecture (e.g., Kyonan), northern parts in Saitama prefecture (e.g., Fukaya), and western parts of Kanagawa (e.g., Hakone).

When the spatial variation in job accessibility is compared across the different impedance specifications, the distributional pattern becomes flatter with longer commuting time. A closer look at the job-access measures indicates that as the travel-time threshold lengthens, the standard deviation and skewness (a measure of the lack of symmetry of a distribution) become smaller. For instance, the access levels around CBDs are decreased with longer travel time. This result is not surprising given that a large body of suburban workers commute to the jobs in CBDs. With the 15-minute threshold, only those who live within or near CBDs can reach the jobs in those districts, and job-access levels in those CBDs are naturally high. This is particularly true for transit commuters, whose travel time is longer than that for auto commuters. With the 45-minute threshold, however, many suburban workers can get to CBD jobs, and job-access levels in central areas decline. The distributional pattern of job accessibility calculated using the gravity model (Figure 3d) is somewhat similar to the pattern for the 15-minute threshold (Figure 3a). This is likely related to the fact that the absolute values of the calibrated gamma are rather large, indicating a relatively large declining effect of commuting time on the number of accessible jobs per worker.

4. Conclusions

Tokyo exhibited a distinctive urban core, having both jobs and workers centered around the central part of the metropolitan area. Jobs were, however, far more centralized than workers. The tabulated statistics indicated that in the central city (the area within 23-ku), there were more jobs than workers, as suggested by the jobs-to-workers ratio of 1.54, whereas in the suburbs (the area outside 23-ku), there were more workers than jobs, as indicated by the jobs-to-workers ratio of 0.75. The 3D maps further revealed Tokyo's monocentric urban structure. The spatial distribution of jobs was highly skewed toward CBDs (the 3-ku area including Chiyoda-ku, Chuo-ku, and Minato-ku), leading to extremely high jobs-to-workers ratios in those districts.

Job accessibility by travel mode was then calculated using the different impedance specifications. Although the computed job-access measures were sensitive to the impedance specifications, some patterns were consistent. One consistent finding is that central-city areas, particularly areas around CBDs, had much higher job accessibility than did suburban areas, as expected. Another consistent finding is that job accessibility for transit commuters was considerably lower than that for auto commuters, although Tokyo offers well-developed public transit systems. For transit users, most suburban zones had access measures less than one, and high-accessibility areas were largely limited to central zones. For auto commuters, on the other hand, most areas had access measures greater than one. The large transit/auto disparity was a rather surprising finding since the disparity was expected to be small.

The great transit/auto disparity was also found for the U.S. metropolitan areas by previous studies (Kawabata 2002; Shen 1998, 2001). Tokyo's situation, however, differs from the U.S. case. In most U.S. metropolitan areas, jobs are greatly suburbanized (the suburb-to-suburb flow is the dominant form of commuting), and public transit systems in the suburbs are poorly developed. Many suburban jobs are practically inaccessible by public transportation, and workers who depend on transit indeed have much fewer accessible job opportunities than do workers who have access to autos.

In Tokyo, on the other hand, the large transit/auto disparity in job accessibility does not necessarily mean that transit commuters have much fewer accessible job opportunities than do auto commuters. Tokyo, where the suburb-to-central city flow dominates commuting patterns, has one of the most developed public transportation systems. With the well-extended transit networks, many suburban workers including those who live far from the central city commute to central-city jobs in spite of long travel. In fact, of those workers who commute from the suburbs to the central city, approximately 16% have 90-minute or longer travel time (TMRTPC 1999). Many people endure such long commutes partly because they put more values on land than on travel cost, and partly because in general companies subsidize transportation cost. For those transit commuters who travel between the suburbs and central city, therefore, what matters would not be the number of job opportunities but the lengthy travel time.

It was interesting to identify suburban centers where auto job accessibility is high but transit accessibility is low. For such suburban centers, the situation is similar to the U.S. case. Tokyo's transit systems are rather radial, and within the suburbs, transit networks are generally not well connected and only slow buses are available. Traveling between suburban locations by public transportation is often burdensome, consuming long travel time. In terms of suburban job opportunities, having access to autos clearly provides an advantage to people getting to and from suburban workplaces.

In fact, auto dependency in suburban areas is much higher than that in the central city. Additionally, while the number of auto trips to or from the central city is slowly decreasing, the number of intra-suburban auto trips is increasing, particularly in the outer suburbs. Between 1988 and 1998, for example, the number of trips made by auto rose by 143% in the northern section of Saitama, by 147% in the southern section of Ibaragi, and by 149% in the southwestern section of Chiba (TMRTPC 1999).

This paper presented a preliminary analysis of Tokyo's urban spatial structure from a perspective of residence, workplace, and transportation. Several future directions are currently planned.

The first direction of future research is to examine longer time for the travel-time threshold function in the job-access calculation. In this study, the three different thresholds of 15, 30, and 45 minutes were used. The values of calculated job accessibility were highly sensitive, although the overall distributional patterns were similar. Given that the average commuting time is 43 minutes and given that 16% of workers traveling between the suburbs and central city have commuting time of 90 minutes or longer (TMRTPC 1999), examining longer thresholds such as 60, 75, and 90 minutes would improve an understanding of the access measures' sensitivity to travel time.

The second research direction is to develop the measurement of job accessibility. In this research, job accessibility was measured in terms of jobs, workers, and transportation. As for Tokyo, such factors as land price, housing provision, transportation policy are likely to play significant roles in determining job accessibility. Access measures would be improved greatly by incorporating these additional factors into the computation of job accessibility.

The third direction of research is to apply the same analytical framework to the U.S. metropolitan areas using newly available Census 2000 and compare the results with the Tokyo case.

The forth research direction is to compare time periods. Investigating not only the current situation but also the direction of changes is important for developing effective planning. The usability of spatial data has been advanced dramatically since 1990 Census. Examining changes between 1990 and 2000 is feasible and of great interest.

These third and fourth directions together can further clarify similarities and differences between urban structures in two countries, which would contribute new data useful for a discussion on sustainable urban form and growth policy.

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Appendix: Gravity Model for Impedance Estimation

In this study, the travel impedance is estimated using a gravity model, which is given by:

$$q_{mij} = \exp(\alpha)\frac{(O_{mi} \cdot D_{mj})^{\beta}}{t_{mij}^{\gamma}}, \qquad \text{(a-1)}$$

where q_{mij} and t_{mij} are the number of trips and travel time between zone *i* and *j* by mode *m*, respectively. O_{mi} and D_{mj} are the number of trips originated from zone *i* by mode *m* and the number of trips ended in zone *j* by mode *m*, respectively. Parameters are represented by α, β, and γ, which are estimated from a logarithmic transformation of Equation (a-1). The provided number of OD trips was expanded using an expansion factor. For the estimation of the parameters, therefore, a generalized least square technique weighted by the number of sample OD pairs is used. Estimation results of parameters are shown in Table (a).

Table (a)

Mode	Car		Rail	
Variables	Parameters	t-value	Parameters	t-value
α	-2.162	-35.990	5.252	107.753
β	0.861	331.485	0.392	215.735
γ	-2.758	-612.295	-1.922880	-324.475
Number of OD pairs	66,552		100,378	
R^2	0.89		0.63	

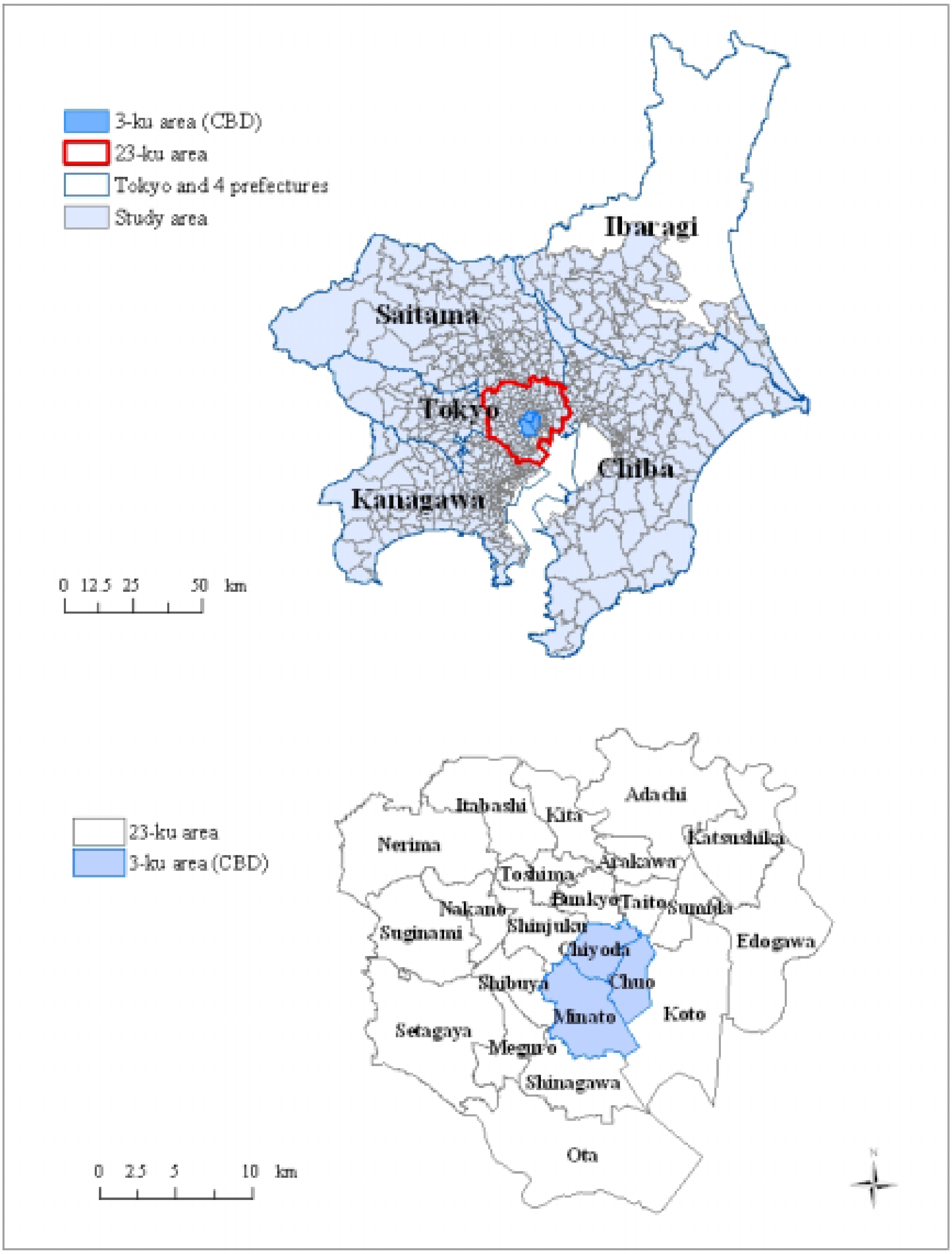

Figure 1 Geographic boundaries for Tokyo metropolitan areas

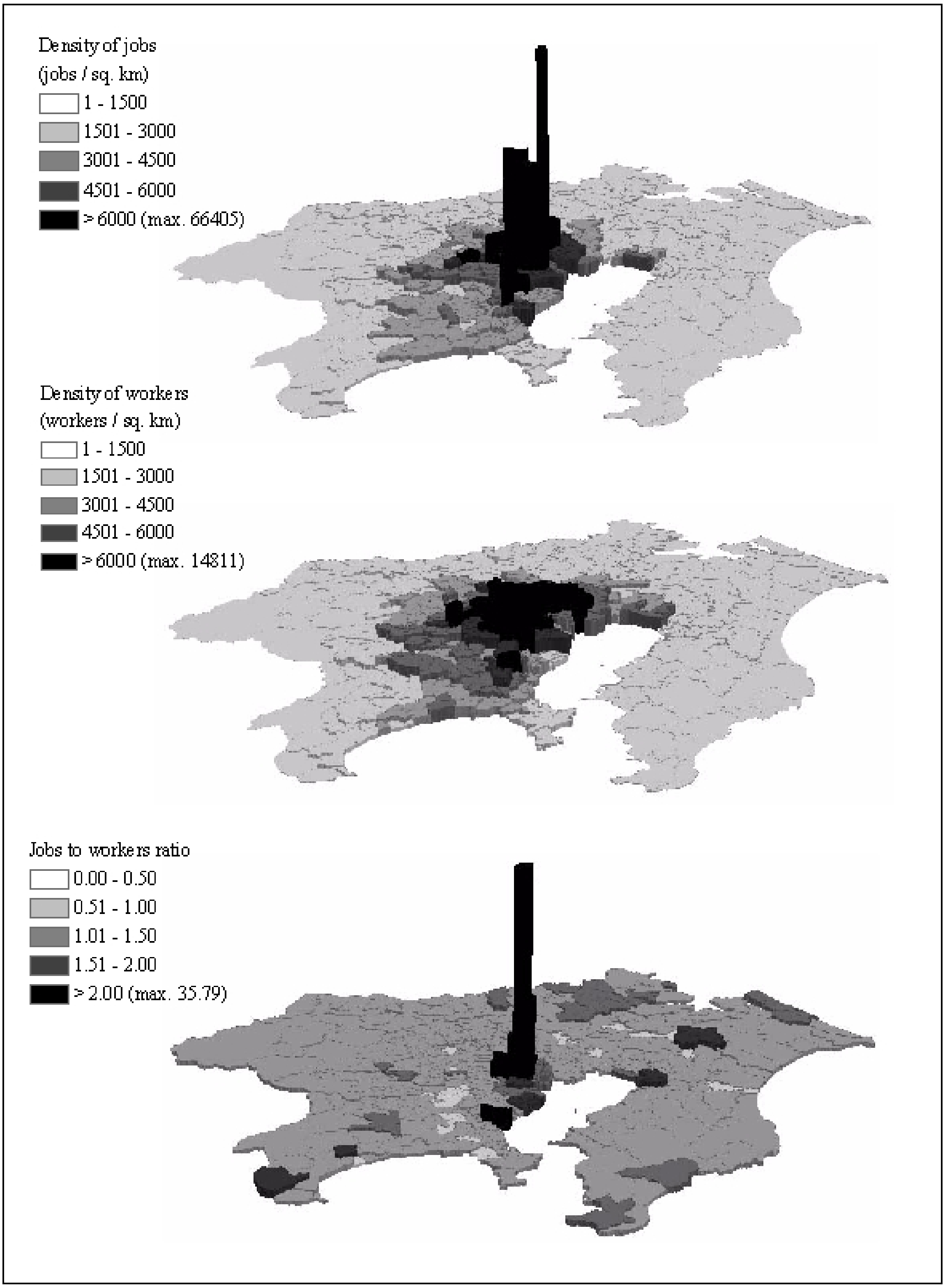

Figure 2 Spatial distributions of workers and jobs in Tokyo metropolitan area

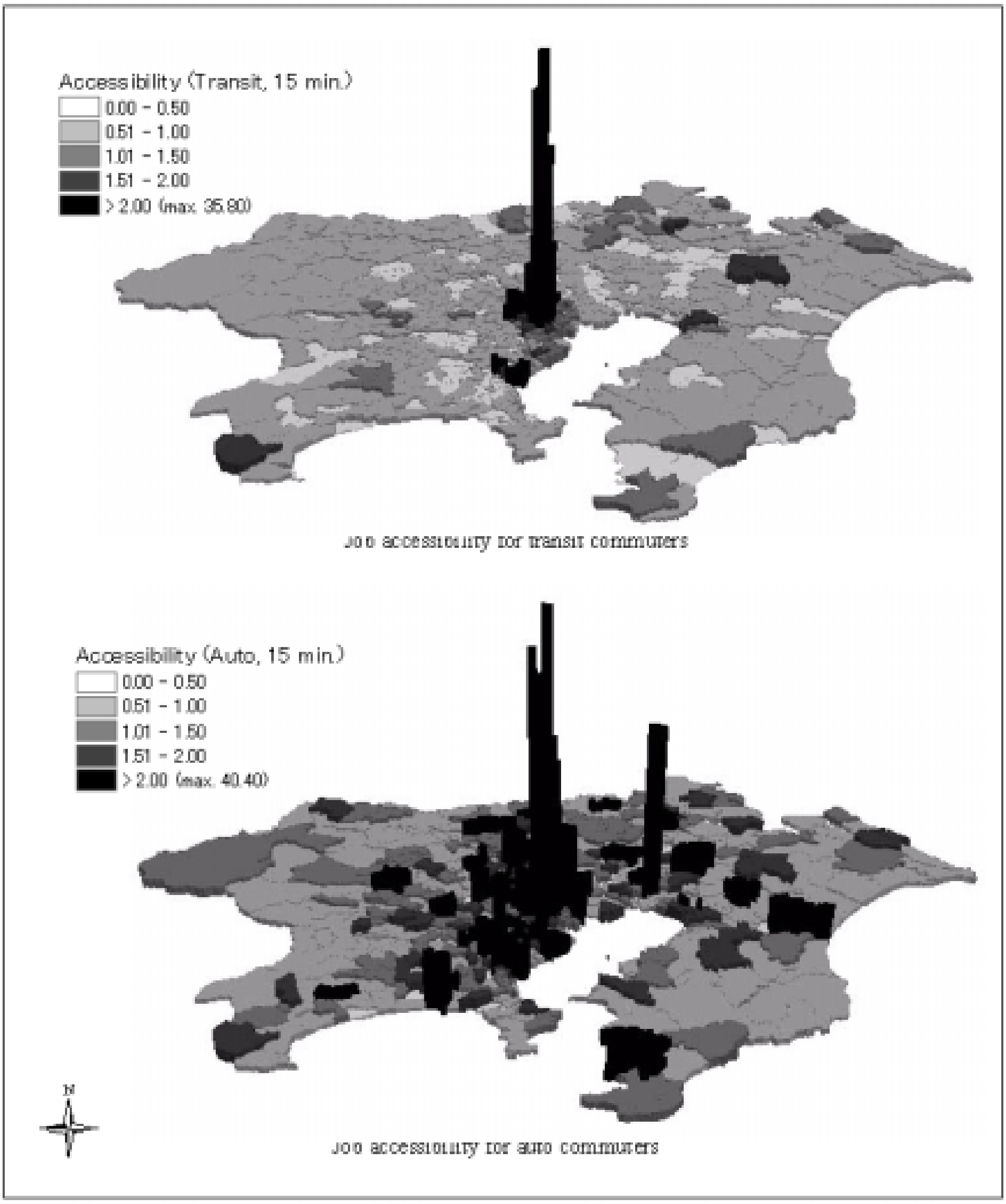

**Figure 3a Spatial variation in job accessibility in Tokyo metropolitan area
(15-min threshold)**

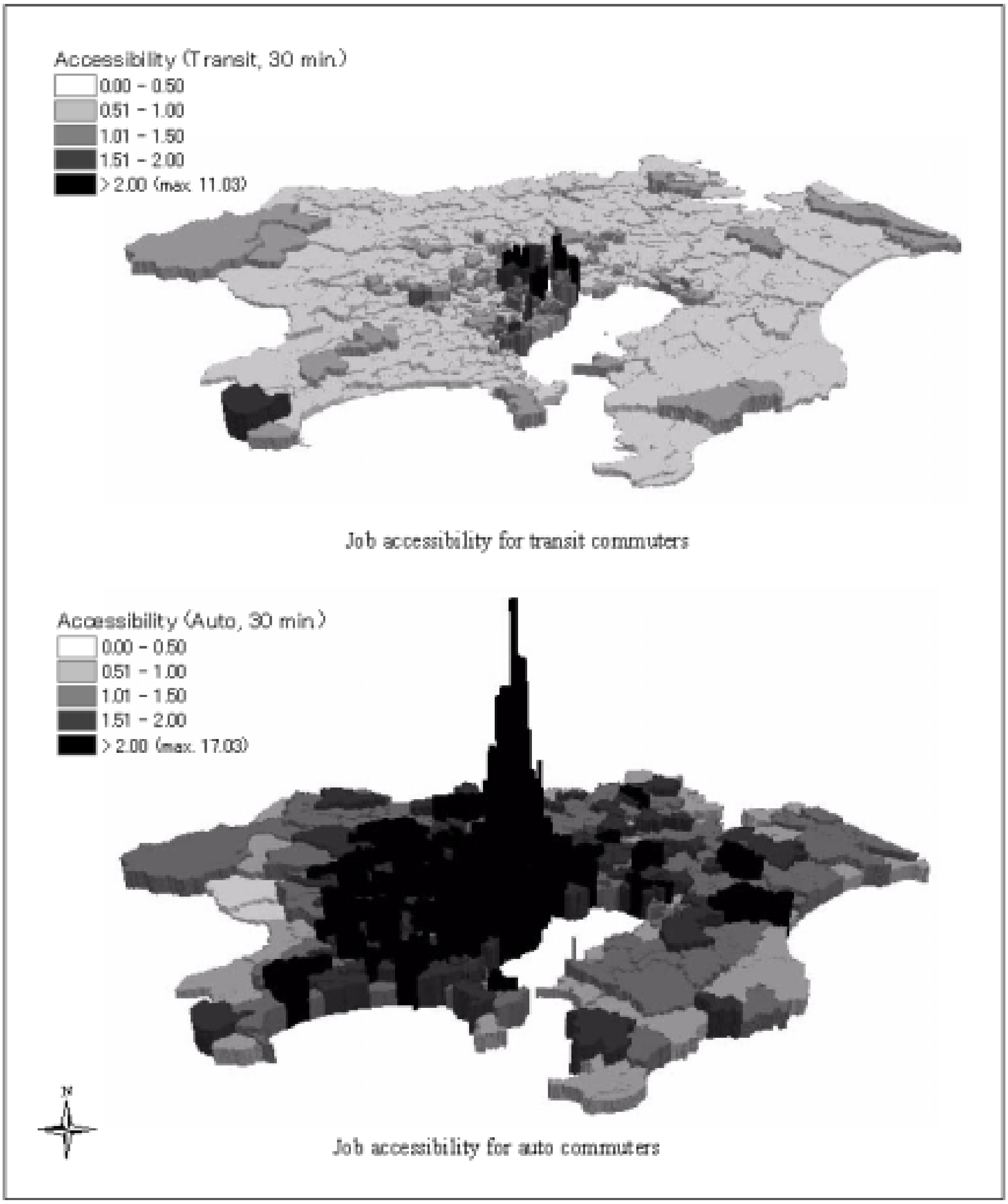

Figure 3b Spatial variation in job accessibility in Tokyo metropolitan area (30-min threshold)

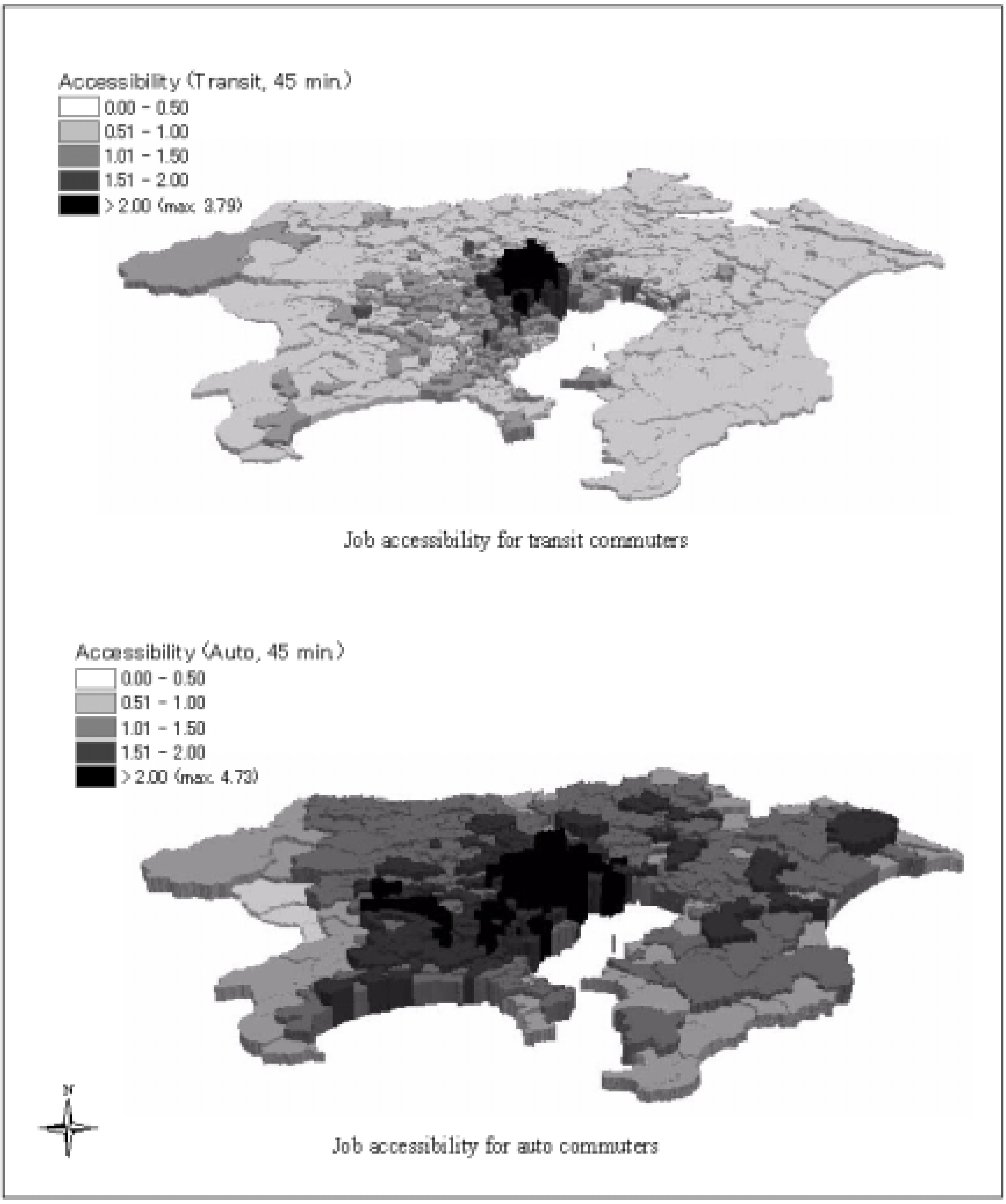

Figure 3c Spatial variation in job accessibility in Tokyo metropolitan area (45-min threshold)

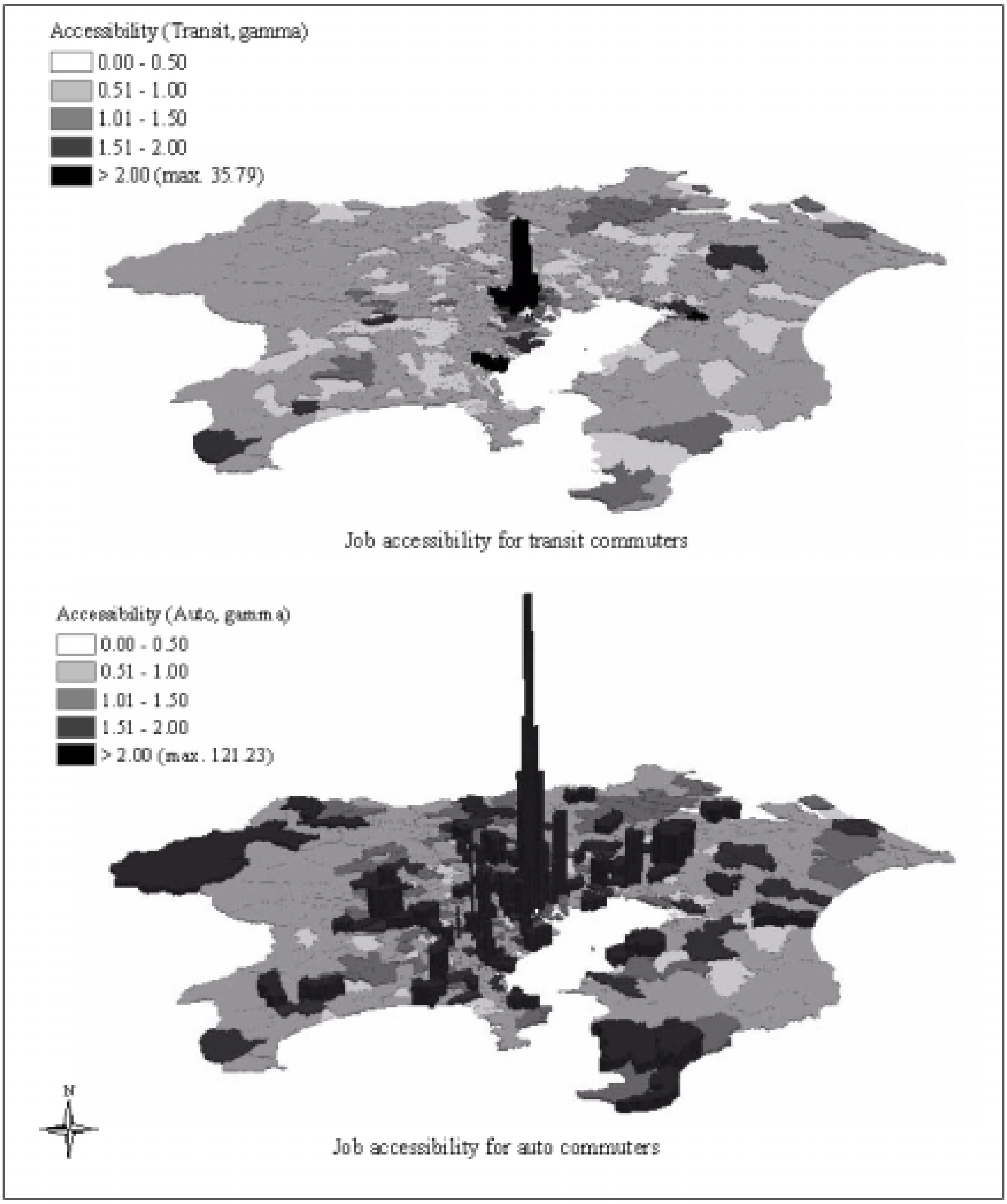

Figure 3d Spatial variation in job accessibility in Tokyo metropolitan area (gamma)