Spatial Aspects of Environmental Equity in Japan

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Abstract

Whilst issues of environmental equity are internationally recognised as a major concern, Japan, a data rich country, has little evidence on whether or not they are present. The purpose of this thesis is therefore to investigate the situation of environmental equity in Japan by developing and employing novel approaches around the use of Geographical Information Systems (GIS).

This thesis firstly presents a GIS-based cross-sectional study of equity in proximity to waste facilities, air pollution exposure and school accessibility in Yokohama city, showing some evidence of disparities between social groups. A longitudinal model of park provision is then developed and presented to investigate whether affluent areas attracted new parks, or new parks attracted affluent people in Yokohama. The results show weak evidence of both processes, and also confirm direct park provision into the least affluent areas may be the most useful policy measure for equity.

A limitation of many equity studies is that they have focused on environmental features that are only measurable in two dimensions. This is despite the fact that many environmental attributes require consideration vertical variations in features, such as building heights. To drive forward this research, a methodology was then developed and is presented to compute access to both sunlight and views in the city of Kyoto. The work illustrates how it is possible to model these three-dimensional attributes for large urban areas using virtual city modelling, and the findings suggest that disparities in access to both of these amenities are present, in the city.

The overall conclusion of the thesis is that inequities are apparent in Japan and that these can be detected and quantified by the development of novel GIS techniques that utilise the rich sources of data present in the country.

Declaration

Thesis length is 39,736 words.

This research thesis is my own original work which was conducted in collaboration with other researchers as follows:

Chapters 1 and *2* were written by Shinya Yasumoto.

Chapter 3 – Shinya Yasumoto was the lead author. Shinya Yasumoto reviewed the literature, collected data, designed the research framework, conducted statistical analyses and wrote the manuscript. Andrew P Jones contributed and advised to design the research framework and reviewed drafts of the manuscript. This chapter is to be submitted as below.

> Yasumoto, S., Jones, A.P. (2011) Environmental equity in a Japanese city: Relationship between social indicators and environmental quality (in Japanese)

Chapter 4 – Shinya Yasumoto was the lead author. Shinya Yasumoto reviewed the literature, collected data, designed the research framework, conducted statistical analyses and wrote the manuscript. Chihiro Shimizu provided data of land and property prices. Andrew P Jones and Chihiro Shimizu contributed and advised to design the research framework and reviewed drafts of the manuscript. This chapter is to be submitted as below.

> Yasumoto, S., Jones, A.P., Shimizu, C. (2011). Environmental equity of park accessibility in Japan: the role of park providers and market mechanisms

Chapter 5 and *6* – Shinya Yasumoto was the lead author. Shinya Yasumoto reviewed the literature, orgranised data for spatial analyses, designed the research framework, conducted statistical analyses and wrote the manuscript. Keiji Yano and Tomoki Nakaya provided data for the virtual city model (i.e. building shape polygons, DEM, and land use data) and census records. Andrew P Jones, Tomoki Nakaya and Keiji Yano advised on the design of the research framework and reviewed drafts of the manuscript.

Chapter 5 was published as follow:

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Chapter 7 was written by Shinya Yasumoto.

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－Contents－

Chapter 1
Initial introduction

Environmental equity is defined as an equal sharing of environmental hazards and opportunities to obtain at least minimum standards of access to amenities regardless of socio-demographic characteristics such as age, ethnicity and income level (EPA 1992, Jones et al. 2009). Throughout the past few decades, issues of environmental equity have been increasingly gaining recognition as an important part of environmental policy frameworks (Liu 2001). Consideration of environmental equity originally stemmed from the social movement against environmental racism in the 1980s in the USA. It was particularly noted that non-white communities were faced with disproportionate environmental risks from the siting of controversial facilities such as hazardous waste dumps, and this phenomenon was clearly demonstrated by several environmental equity studies performed at the time (e.g. GAO 1983, Zimmerman 1993). Conceptual and research frameworks concerning environmental equity were then expanded to incorporate the aims of investigating and reducing the unequal distribution of a wide range of environmental metrics between social groups, including proximity to environmentally risky facilities, air quality, and access to various types of amenity such as parks and green spaces.

A notable trend in equity studies is that, since the 1990s, Geographic Information Systems (GIS) techniques have increasingly contributed to their methodological frameworks. This is principally because they provide powerful tools for investigating the spatial distribution of environmental quality between populations (Liu 2001, Manntay 2002, Nicolls 2001). GIS are defined as “automated systems for the capture, storage, retrieval analysis, and display of spatial data” (Clarke, 1995, pp13). By applying GIS, the quality of data and efficiency of analytical methodologies available can be improved and much research has made use of them (e.g. Mitchell and Dorling 2003, Jones et al. 2009). Recent significant progress has been made, both in terms of GIS functionality and the availability of computing power, giving this technique the potential for wider use, and it is the adoption of these advances that form a core component of this thesis.

Despite its long history, it is noteworthy that interpretation of the findings of environmental equity research is often difficult. In part this is due to three key limitations of current equity studies. Firstly, although issues of environmental equity are internationally recognised as a major concern (Kruize et al. 2007, Serret and Johnstone 2006), much of the research evidence comes from the USA. These is a country where levels of social segregation are much higher than observed in many other nations and because of this there are limitations in generalising findings to other settings since each country may have different socio-cultural backgrounds and perspectives (Kruize et al. 2007, Pearce 2006, Liu 2001). More recently in some other areas, such as Europe and Oceania, several equity studies have been conducted, although the number of them is still much less than in the USA. Examples include Mitchell and Dorling (2003) in the UK, Kruize et al. (2007) in Holland, and Pearce et al. (2006) in New Zealand. Nevertheless, very limited is known about the situation of environmental equity in Asian countries, such as Japan, and therefore the sample areas of equity studies are still greatly biased (Pearce 2006).

Secondly, the methodology of equity studies is dominanted by cross-sectional designs, and a limitation is that these works focus on a single point in time, and describe only one outcome. Hence it is not possible to use this study design to capture the causes and processes that lead to the generation of environmental inequities (Mohai 2008, Pastor et al. 2001, Saha and Mohai 2005, Boone et al. 2009). It is argued that longitudinal studies hold particular potential to provide better information to direct environmental policies that may be developed in an attempt to remedy inequities between communities. However, there are two key drawbacks of many existing longitudinal analyses (Mohai 2008; Saha and Mohai 2005). One is that geographic boundaries of census areas change over time, and thus it is hard to conclude whether neighbourhood change has occurred as a result of environmental change or boundary change. A second problem is that most longitudinal studies focus on time-dependent distributions of environmental risks, but not amenities. Issues regarding equity in access to amenities are being increasingly focussed upon by researchers and urban planners (Boone et al. 2009), and therefore it is important to examine the processes of inequity generation so that policy measures may be developed to remedy any disparities present.

A third issue that is addressed by this thesis is that issues of equity regarding some particular environmental disamenities and amenities are still untested. The most frequently examined environmental attributes are proximity to environmentally risky facilities (e.g. GAO 1983) and air pollution exposure (e.g. Korc 1996). Recently a range of other environmental qualities, such as exposures to noise (Brainard et al. 2004), accessibility to parks (Jones et al. 2009), green spaces (Comber et al. 2008), and schools (Talen 2001) have been tested, but there are several other environmental attributes that have never been investigated from equity perspectives. These include environmental attributes which require particular consideration of vertical variation in topographic features, in particular building heights. Both access to sunlight and view are such examples; they are essential for quality of life, well-being and human health, and both are investigated in this thesis.

Building upon these considerations, this research principally aimed to examine environmental equity in the data rich but evidence poor country of Japan. Specifically, this thesis describes three major research topics: Investigating the cross-sectional situation of environmental equity in Japan, examining the importance of longitudinal modelling on environmental equity studies, and exploring the potential of virtual city models, which integrate vertical variation in urban contexts.

Thesis structure

Chapter 2 contains a review of the literature regarding the history of environmental equity and the implications of the development of GIS on equity studies, with a focus on the Japanese socio-cultural background and quality of available datasets. The four subsequent chapters present the analyses undertaken.

Chapter 3 examines the cross-sectional situation of environmental equity in the distribution of three environmental qualities (proximity to hazardous industrial waste management facilities, exposure to air pollution, and accessibility to public elementary schools) in Yokohama. These study subjects were chosen because proximity to environmentally risky facilities and air pollution exposure are arguably the most frequently examined equity issues in the international equity literature (Liu 2001, Pearce et al. 2006), whereas good accessibility to schools is known as one of the most important environmental amenities (Talen 2001).

Chapter 4 investigates how taking a longitudinal view contributes to further understanding environmental equity. The study presented focuses on the longitudinal association between the siting of public parks and social indicators to identify the importance of the roles of park providers and market mechanisms throughout an 18-year time frame in Yokohama. The concern is that parks may be disproportionately opened among different communities due to unequal political power between them (Boone et al. 2009) or alternatively that cheap land prices in less affluent areas may attract park siting by providers. Conversely, if the provision of parks increases land and property prices, only socially advantaged population will move in these areas (Jones et al. 2009), thus magnifying environmental inequities. These 'which came first?' hypotheses were tested in the chapter. Grid based census records published every 5 years were employed for this research to minimise the effect of boundary changes on estimation of neighbourhood change.

Chapters 5 and 6 present new environmental equity analyses using a novel and cutting-edge virtual city modelling system, 'Virtual Kyoto' developed by Ritsumeikan University, Kyoto. A virtual city model is a three dimensional city representation which depicts realistic buildings and provides a range of services, functions, and information (Dodge et al. 1997). It has previously been argued that there are two key potential applications of virtual city models: visualisation and three dimensional spatial analyses (Kurakula and Kuffer 2008, Wolff and Asche 2008). This research thesis particularly illustrates the feasibility of these novel forms of analyses by using virtual city models to examine equity in the accessibility of sunlight and views, both of, which require to consider vertical variation including building heights to be calculated (Tanaka et al. 2006, Sander and Manson 2007). To our knowledge, socio-demographic distributions of these environmental qualities have not been investigated yet, although both are known to contribute to public health and more generally the quality of life in Japan (Tanaka et al. 2006, Thompson et al., 2010).

Chapter 7 summarises the findings of this thesis, both in terms of the situation regarding environmental equity in Japan and how the application of the methodologies developed for this thesis may contribute to equity studies. A consideration of the implications of the conclusions, the limitations of the work presented, and recommendations for future study are provided.

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Chapter 2

Literature review

Abstract

This chapter reviews the literature regarding the history of environmental equity and the implications of the development of GIS modelling for equity studies, including both longitudinal modelling and virtual city models. Environmental equity has a long history; over the last few decades, the importance of equity has become increasingly recognised throughout the international research field. The development of GIS has significantly contributed to improving the quality of the data and methodological analyses of equity studies. The further development of in-depth GIS models is expected to play a vital role in providing better information on environmental equity. Longitudinal equity studies based on 'which came first' hypotheses that focus on disparity's generation process can better inform us of the policy implications required to remedy the inequities. Virtual urban models, the accurate and cutting-edge city modelling systems, can be used to measure environmental qualities, which must include considerations of vertical variations (including building heights). However, it should be noted that the research design of a Japanese equity study ought to be adjusted to the socio-cultural background of and the data availability in this country.

1. Environmental equity

Over recent decades, the concept of environmental equity has gained increasing importance worldwide. Environmental equity is defined as the equal sharing of environmental risks and of equal-opportunity of access to environmental amenities across socio-demographic groups (EPA 1992, Jones et al. 2009). The concept of environmental equity emerged in USA at the beginning of the 1980s as a result of the 'environmental equity movement'. The history of the environmental equity movement is strongly related to public opposition to the disproportionate siting of environmentally risky facilities (e.g. hazardous waste facilities and landfills) in areas inhabited by minority communities.

In USA, in the 1960s, there was growing public concern about environmental degradation, including air and water pollution as well as ecological destruction (Dunlap and Mertig 1992). During this period, hazardous waste facilities were more likely to be sited in areas inhabited by white communities, and not in those inhabited by minorities (Saha and Mohai 2005). In addition, there was little scientific knowledge about the risks of waste facilities, and there was low public awareness of the same (Rabe 1994, Dunlap and Mertig 1992). Furthermore, the Civil Rights Movement, which aimed to end racial discrimination and restore voting rights for all, had taken hold throughout the country during this period. The environmental equity movement can be seen as one extension of the Civil Rights Movement (Dunlap and Mertig 1992).

During the 1970s, public opposition to the siting of waste facilities in certain areas increased on account of more widespread awareness of environmental risks from hazardous waste dumping (Bullard 1990). The movement against these facilities was advocated by the public and by grassroots activists, and strong public opposition was witnessed in several localities. This public opposition strongly influenced decisions pertaining to the siting of these facilities (Saha and Mohai 2005). However, initially, the members of this movement were dominantly white middle class (i.e. relatively wealthy and politically empowered citizens); politically disempowered communities and minority groups were not involved (Dunlap and Mertig 1992). Consequently, environmentally risky facilities ended up being disproportionately sited in areas inhabited by minority communities. Later, the potential health risks of the resulting concentration of environmentally risky facilities in such areas became a controversial issue (Bullard 1990).

The 1980s thus witnessed the emergence of the environmental equity movement, which aimed at remedying the racial disparities in the burden of environmental risks shared by different communities. Although some researchers initially did not believe in the existence and severity of such environmental inequities (Mohai 2008), a number of empirical studies conducted at the time furnished evidence of these disparities (Liu 2001). For example, one of the most influential studies was that conducted by the UCC (1987), which provided statistical evidence of relationships between proximity to commercial hazardous waste sites and areas inhabited by the poor and minorities; the findings of this study attracted the attention of both authorities and researchers.

These social trends changed the political climate in the US as well. Local authorities made attempts to remedy the abovementioned disparities in reaction to public concern about environmental inequity (Dunlap and Mertig 1992). This, in turn, led to efforts at the national level to combat these disparities. A significant milestone in this movement was Executive Order 12898, issued by President Clinton in 1994 (President Clinton 1994). This order aimed at achieving environmental equity by encouraging federal agencies to make strategies to mitigate against environmental inequity. As a result, strategic planning, public involvement, information dissemination, and environmental equity studies are all considered as important parts to combat against racial and socio-economic disparities in the US (Liu 2001).

Later, during the 1990s and 2000s, the concept of environmental equity drew interest outside the US as well (Mitchell 2005), and several equity studies were conducted in, for example, European countries such as the UK (Friends of Earth 2001) and the Netherlands (Kruize et al. 2007); Canada (Buzzelli et al. 2003); and Oceania (Pearce et al. 2006). These studies also reported results similar to the findings in the US: environmental risks were disproportionately placed near socially disadvantaged communities.

Also during this period, the concept of environmental equity was expanded to realise equity not only in terms of the burden of environmental risks but also in terms of having equal-opportunity standards to access amenities such as public parks and green spaces (Boone et al. 2009). Studies which focused on the socio-demographic distributions of amenities found that these were also disproportionately sited near socially advantaged communities, leaving disadvantaged groups with limited opportunities (Comber et al. 2008, Jones et al. 2009, Boone et al. 2009).

Pearce (2006) described two main reasons why environmental equity should be carefully considered. First, environmental inequity can violate social efficiency. Unequal distributions of environmental qualities (i.e. problem of outcome inequity) may magnify the problems of public health and poverty, and, as a result, social costs may increase. Pearce (2006) stated that the unequal burden of environmental risks between populations having different income levels can potentially more negatively impact overall public health relative to the situation of equal burden of environmental risks. Furthermore, disamenities are often located near poor or other socially disadvantaged communities, and they drive down land prices in these areas. As a result, the people living in these areas could become poorer, and their living environment would worsen (Been 1994, Saha and Mohai 2005).

Second, unequal distribution of environmental risks or amenities might be caused by an unfair process (i.e. problem of procedural inequity). Several authors have argued that, if disproportionate distributions of amenities or disamenities are generated as a result of people’s free choice, then there may be no problem (Pearce 2006, Boone et al. 2009, Pastor et al. 2001). However, such circumstances are actually rare. It is observed that unequal political power between different population groups causes the disproportionate provision of both disamenities and amenities (Pastor et al 2001, Hamilton 1993). Also, socially disadvantaged populations occasionally suffer from discriminative practices, such as job or housing discrimination (Nakagawa 2001). Furthermore, socially deprived people may not have adequate access to information about potential environmental risks in their areas. These factors can easily violate ‘people’s free choice’.

Despite these present international trends and important reasons for realizing environmental equity, very little is known about the level of environmental equity in Japan. Nevertheless, social equity issues (such as poverty) and aging society are becoming increasingly controversial in this country (Tachibana and Urakawa 2006, Iwata and Nishizawa 2005, Tachibanaki 2006, Yamano 2008). These social trends may generate serious magnitude of environmental inequity.

The current situation in Japan may be somewhat similar to that in the UK around the year 2000 (Mitchell 2005). Although the UK did not witness substantial environmental equity movements which were driven by the public or by grassroots activists, both researchers and authorities actively began considering this issue from the early 2000s (Mitchell 2005). Japan may go along a similar path to the UK; although an environmental equity movement might not emerge, intensification of social equity issues may, in turn, bring environmental equity issues to the notice of the authorities. It is also important to remember that neglecting environmental equity standards may worsen the problem (Burke 1993).

There is some debate regarding the terminologies related to the environmental equity issue. The terms ‘environmental equity (EE)’ and ‘environmental justice (EJ)’ are both frequently used in the literature, but their definitions vary among authors. Harding and Holdren (1993) use the terms synonymously. Mitchell (2005) states that EE is the socio-demographic distribution of environmental quality, whilst EJ measures to what extent the process of generating disparity is unfair.

However, in this thesis we use the term ‘environmental equity’ only and treat ‘EE’ and ‘EJ’ synonymously (Harding and Holdren 1993). Chapters 3, 5, and 6 present cross-sectional views of the social distribution of environmental qualities and are thus ‘EE’ studies according to the criteria suggested by Mitchell (2005). Chapter 4 is a longitudinal study, however, which focuses on the time-dependent process of generating disparity; it is thus an ‘EJ’ study. The whole thesis, then, offers mixed research using both EE and EJ. Hence, for the sake of simplicity and consistency, we chose to use ‘environmental equity’ only rather than ‘environmental justice’.

2. Contribution of Geographic Information Systems (GIS)

Methodological improvement on environmental equity studies is important since it can lead to more accurate evaluation of the magnitude of disparities between different social groups as well as more focussed hypotheses to test reasons and causal process for generating environmental inequity (Mohai 2008). For these purposes, Geographic Information Systems (GIS) have a key role to play. From 1990s, GIS has increasingly contributed to the development of environmental equity analyses (e.g. Sheppard et al. 1999, Nicholls 2001). GISs are defined as ‘automated systems for the capture, storage, retrieval, analysis, and display of spatial data’ (Clarke 1995, p.13).

Since the principal research framework of equity study is investigating the spatial relationships between the distribution of environmental qualities and population characteristics, GIS, which are information systems especially designed for spatial analyses (Takasaka 2002), have the potential to play a vital role in equity studies. The contribution of GIS for environmental equity analysis has several parts (EPA 1998).

Firstly, GIS can efficiently shed light on the components of environmental equity issues by clarifying the locations of socially disadvantaged groups and the spatial distributions of potential environmental risks or amenities. GIS also provide effective methods to capture and measure various kinds of environmental features, and the obtained measures can be stored within GIS. For example, by considering the sources of pollutants such as road networks, the magnitude of air and noise pollution can be estimated and recorded using GIS (e.g. Brainard et al. 2002, Kurakula and Kuffer 2008).

Secondly, GIS can easily overlay locational information about population, quality of environment, or other specific local characteristics on more than one map. More specifically, GIS can identify the spatial relationships between a given population and each environmental quality. For example, using GIS, it can be calculated to what extent hazardous facilities/amenities are proximal from the communities of the target population (Cutter 1996, Manntay 2002, Talen 2003).

Thirdly, GIS provide a visual interpretation of environmental equity/inequity (Ogneva - Himmelberger and Cooperman 2008, Manntay 2002). This function may be particularly useful for policy makers to make decisions, and may also draw the public's attention.

Fourthly, GIS efficiently provide alternative results when users input different parameters to investigate their sensitivity (Cutter et al. 1996), or when they model 'what if scenarios' to simulate and compare different situations that may affect the outcome of equity (Mitchell 2005).

As an example of the methodological improvement provided by GIS, Talen (2003) discussed the potential of GIS-based road network analysis to calculate accessibility to an amenity from each community. Although it was computationally intensive for the personal computers at that time, she stated that road network distance is a better indicator of accessibility than simple Euclidean distance. Before GIS became publically available, opisometres were used to calculate road network distance. However, as Shimizu (2004) showed, while the method using opisometres has the potential to yield significant errors when measuring road network length, GIS can provide a significantly improved measure of road network length in terms of both accuracy and efficiency.

These strengths of GIS have been contributing to the development of environmental equity studies. However, both current GIS and GIS-based equity studies have further potential in a different and novel dimensions. This research thesis explores the above potential of in-depth GIS models for a better understanding of environmental equity and an improvement of methodological aspects in equity analysis.

3. Longitudinal modelling of environmental equity

The longitudinal modelling of environmental equity is an important research area that can be explored through GIS (Maantay 2002). Most equity studies have investigated the *current* socio-demographic distribution of environmental qualities (e.g. GAO 1983, Zimmerman 1993), but their limitation is that they focus on only one outcome and do not sufficiently clarify the causal processes that generate environmental inequities (Been 1994, Saha and Mohai 2005, Boone et al. 2009). Longitudinal modelling is an alternative approach that is expected to provide better implications for remediation measures to reduce environmental disparities (Liu 1997). Remediation measures based on inappropriate assumptions about what generates disparity processes may be inefficient or costly (Shaikh and Loomis 1999); thus, understanding environmental equity from a time-dependent view is essential.

The ‘which came first’ hypothesis is one of the most frequently examined research questions in longitudinal equity studies (Pastor et al. 2001, Boone et al. 2009). This hypothesis explores the process of generating environmental inequity and inquires whether environmentally risky facilities are disproportionately sited in socially disadvantaged areas or if disadvantaged populations have been moved into such areas after the siting of a hazardous facility. These two processes may work in combination to generate disparity. The former process, disproportionate siting, may be caused by an unequal distribution of political power among communities (Pastor et al. 2001). Alternatively, cheap land prices, compensation, or labour may motivate developers to site a new hazardous facility in a certain area (Hamilton 2006). If either of these siting patterns are observed, authorities should review the siting process, examine the factors that might be contributing to the disproportionate placement of environmental risk (Pastor et al. 2001, Mohai 2008), and encourage a more equal placement of facilities. A re-examination of zoning and an encouragement of public participation among the socially disadvantaged may be efficient in reducing disproportionate siting (Pastor et al. 2001).

On the other hand, to address environmental inequity caused by the latter process (i.e. a disadvantaged population moving near a sited hazardous facility), the authorities may need to intervene in the unregulated market mechanisms (Mohai 2008). Moving amongst the disadvantaged population could have been caused by lowered land prices as a result of disamenity siting or by housing discrimination against socially weak groups, such as the aged (Nakagawa 2001). To remedy these problems, income redistribution programmes (Been 1994), ensuring access to information about the potential environmental risks in each area, specific frameworks to combat housing discrimination (Nakagawa 2001), and the careful siting of low-income housing (Been 1994) all have roles to play. In the long term, providing adequate educational opportunities to socially disadvantaged groups may also contribute to reducing environmental inequity (Shaikh and Loomis 1999).

The importance of the ‘which came first’ hypothesis is repeatedly emphasised in many equity studies, including cross-sectional and longitudinal ones (Brainard et al. 2002, Boone et al. 2009, Mohai 2008). Nevertheless, it should be noted that longitudinal studies suffer from two limitations. Firstly, there are very few of them, and their results are inconsistent (Mohai 2008, Saha and Mohai 2005, Liu 1997). For example, Pastor et al. (2001) investigated the siting of toxic facilities and minority move-ins in Los Angeles County over three decades. They found that the effects associated with disproportionate siting appeared to be of a greater magnitude than those due to the migration of minority groups in the study area. This result was supported by the findings of other studies, such as Hamilton (1993).

Conversely, some studies have found that socially disadvantaged populations have tended to move in after the siting of the environmental risk (Been 1994, Stretesky and Hogan 1998). The findings of other studies support neither of the two perspectives (Been and Gupta 1997, Oakes et al. 1996), whilst Saha and Mohai (2005) found that a combination of disproportionate siting and post-siting population changes contributed to disparities between the 1970s and the 1980s in the American state of Michigan.

The results have been contradictory and longitudinal studies have been rare mainly because of limited data availability (Mohai 2008, Saha and Mohai 2005). Old data on population measures and environmental quality are sometimes lost, not yet digitised, or of poor quality, making it difficult to conduct longitudinal studies (Liu 2001, Saha and Mohai 2005). Furthermore, administrative area boundaries change over time, which makes it difficult to analyse whether changes in socio-demographic characteristics are caused by population shifts or boundary changes (Saha and Mohai 2005, Mohai 2008, Liu 2001).

Secondly, most longitudinal studies of environmental equity have focused on the socio-demographic distributions of controversial facilities only, while time-dependent changes in the distribution of amenities have been rarely examined. To our knowledge, the 'which came first' hypothesis has yet to be tested on the issue of equity in access to amenities.

Chapter 4 of this thesis develops a longitudinal model of park provision employing census records published each five years and based on a 1 km grid tabulation. One of the strengths of the grid-based census tabulation employed is that the grid boundaries do not change over time, allowing us to overcome the problem of boundary changes. This modelling could contribute to a better understanding of environmental equity in amenity accessibility, the underlying process of disparity generation, and their policy implications.

4. Virtual city models

Although the socio-demographic distributions of a wide range of environmental qualities have been examined, most previous studies are based on two-dimensional spatial analysis including proximity to both disamenities and amenities (Kruize et al. 2007, Manntay 2002). However, an obvious limitation of these models is that they cannot integrate information pertaining to the variation of height in the study area. To measure other specific environmental qualities, such as access to sunlight and view, it is essential to employ urban modelling which also integrates building height. Virtual city modelling shows promise as a novel solution for calculating these specific environmental qualities.

A virtual city model is defined as a three-dimensional urban representation which depicts realistic buildings and provides a wide range of services, functions, and information (Dodge et al. 1997). In the 1990s, the availability of increasing computing power and the demand for digital information pertaining to the urban environment, people within the city, and interactions between the two (Lovett and Appleton 2007) facilitated the development of digital city modelling and representation methodologies (Evans et al. 2005, Hudson-Smith 2008). Initially, computer game developers, architecture firms, and Computer Aided Design (CAD) software techniques drove developments within this field (Evans et al. 2005). Recently, three-dimensional GIS and virtual reality techniques have also been applied, and these are expected to play important roles in research as well as urban planning (Evans et al. 2005, Shiode 2001, Yano et al. 2007).

Virtual urban modelling shows great promise for visualisation as well as a variety of spatial analyses (Kurakula and Kuffer 2008). In many cases, three-dimensional visualisation is easier to understand than two-dimensional maps (Evans et al. 2005). Furthermore, these urban modelling techniques provide a GIS layer which includes information pertaining to the variation in height across a city; this information is suitable for GIS-based spatial analyses which require consideration of the building height.

There already exist a number of studies on the potential of virtual city modelling across countries. Nakaya et al. (2010) illustrated several uses: creating an online archive of Japanese traditional arts and culture; conducting landscape simulation; and generating 3D hazard maps in Kyoto, Japan. Wolff and Asche (2008) developed a 3D city model that represents the urban landscape of Berlin, Germany, and provided a three dimensional visualisation of the amount of traffic on each road segment, distributions of socio-demographic characteristics and urban threats (defined as locations of vulnerable buildings). The Centre for Advanced Spatial Analysis (CASA) at University College London, the UK, developed the 'Virtual London' model that depicts the urban landscape of London. The research team in CASA demonstrated several applications of virtual city modelling (e.g., simulations of changes in sea level and air pollution; virtual social spaces on the Internet, a digital urban environment based on virtual city modelling that provides communication space for internet users; and virtual urban information systems for developers looking for sites for their development plans, for authorities of urban planning, and for tourists and residents seeking their destinations) (Evans et al. 2005, Dodge et al. 1997, Hudson-Smith 2008).

In Chapters 5 and 6 of this thesis, we employed a Japanese virtual city model, called ‘Virtual Kyoto’, developed by the GIS research team at Ritsumeikan University, Kyoto (Figure 2.1). As shown in this figure, the Virtual Kyoto model has very accurate and realistic building models, which play the most important role for spatial analyses. This model is based on commercially available building polygon data—MAPCUBE—which is provided by Increment P, Co., CAD Centre, Co., and PASCO, Co. The height information within MAPCUBE is generated by LIDAR technology; the vertical accuracy is corrected within ±15 cm (Yano et al. 2007), and the horizontal scale is 1/2500.

Figure 2.1. Example of building model of Virtual Kyoto

The GIS research team at Ritsumeikan University also conducts a wide range of studies and fieldwork surveys to collect information on Kyoto’s landscape at present and in the past (Yano et al. 2007). The team collected information on locations and attributes of historical buildings and other cultural objects, which are particularly useful for landscape research.

These attributes of Virtual Kyoto provide an excellent potential for the calculation of both access to sunlight and view of scenic amenities, which are important environmental qualities for general health and quality of life (Tanaka et al. 2006, Thompson et al. 2010). However, empirical studies that investigated the socio-demographic distributions of these amenities are still limited.

5. Socially disadvantaged groups in Japan

It is important to acknowledge that each country has a different socio-cultural background, and the availability of data varies in different contexts and thus, the research framework of an equity study should be aligned accordingly (Mitchell and Dorling 2003, Kruize et al. 2007). The population measure of disadvantaged groups may differ across countries with regard to their social background (Mitchell and Dorling 2003).

The choice of population measures could be an issue that particularly needs to be considered in Japan; namely, who are the socially disadvantaged groups? In the American context, Liu (2001) stated that important social indicators to identify the disadvantaged groups which need to be particularly considered from the perspective of environmental equity could be age, poverty (or affluence) levels, and ethnicities/races. Several equity studies in the US and other countries (e.g. EPA 1992, Maantay 2007) support that certain social groups are disadvantaged populations and suffer in a disproportionately unhealthful environment, but the data for some social indicators are not available at small census area level in Japan and further, some social groups may not be considered as disadvantaged groups in the Japanese context; we have discussed this facet later.

In this thesis, we particularly focus on age groups and poverty (and also affluence) levels between communities by considering the Japanese socio-cultural background as well as the availability of data. The main source of information on population characteristics used is census data, which is recognised as the best data source of population measure for equity studies (Liu 2001), and several equity studies that were conducted outside Japan have also employed it. The Japanese Census, whose surveys are conducted every five years by Japan Ministry of Internal Affairs and Communications, collects data on a wide range of population measures regarding the characteristics of people and housing (Kurasawa and Asakawa 2004). We particularly employed tabulations on the basis of both census grids and small census areas.

The first target population in this thesis is disadvantaged age groups, particularly the elderly or very young people. These groups are known to be vulnerable and susceptible owing to their reduced or immature immunological systems and inactive life patterns (Sexton et al. 1993, Filleul et al. 2004, Pikhart et al. 1997). They also tend to be less mobile (Talen 2003) and thus, this may have an adverse effect on the evacuation procedure during hazards, or they may have less access to the opportunities in their neighbourhood. Housing discrimination against the elderly was also observed in the Japanese context (Nakagawa 2001) and therefore, these practices might contribute to fostering environmental inequity.

The second target population is the economically deprived population as well as the affluent people. People with lower job status, income levels, or educational qualification are potentially deprived population, whereas people with high job status, income level, or educational qualification are recognised as affluent groups. Poverty (or affluence) is one of the most frequently tested population measure in equity studies across countries (Liu 2001). It is known that an impoverished population is likely to disproportionately endure the impact of environmental risks (EPA 1992), while they have limited access to amenities (Kruize et al. 2007). Conversely, the affluent populations tends to enjoy a good environment, and they also have additional potential to politically influence the location-related decision of controversial facilities (Saha and Mohai 2005), or they can afford to move away from neighbourhoods with environmental risks (Been 1994) as well as to move into environmentally advantaged areas (Jones et al. 2009).

Additionally, it should be noted that an impoverished population is also likely to be vulnerable owing to their poor health status and limited access to medical care (O'Neill et al. 2003, UCC 1987). Therefore, the adverse effect of the burden associated with unhealthy environment may intensify in these groups. In the international context, there are numerous measures of poverty or affluence; for example, income level, job status, educational level, social deprivation index, and quality of residences (see Liu 2001, Brainard et al. 2002). In this thesis, we extracted job status and educational levels as indicators of poverty/affluence from the Japanese census records because these two are among the most reliable measures (Kurasawa and Asakwa 2004, Brainard et al. 2002), whereas the other data such as social deprivation index are unavailable in Japan.

Although most American environmental equity studies majorly focus on race and ethnicity (UCC 1987, Bullard 1990), these variables may not be important indicators in the Japanese context. In spite of the so-called ‘melting-pot of races’, the US has people from diverse racial and ethnic backgrounds, and non-white groups are especially likely to be disproportionately posed by environmental risks or to be deprived of opportunities. However, the number of foreigners is fewer in Japan in comparison with the number in the US and some European countries, such as the UK (OECD 2002). Even in the UK, several authors noted that ethnicity is not an important target group in the environmental equity study framework since the social equity in Britain rather focuses on poverty, whereas public pressure to address racial disparity is almost absent in this country (Mitchell 2005). Moreover, the relationship between racial bias and its effect on the level of poverty is still unclear (Mitchell and Dorling 2003, Stephens et al. 2001). Therefore, Mitchell (2005) suggested a focus on vulnerable populations least able to help themselves: disadvantaged age groups and the poor. In fact, several equity studies in Europe focused only on age groups and poverty levels of the population, but not on ethnicity or race (e.g. Mitchell and Dorling 2003, Wheeler and Ben-Shlomo 2005, Kruize et al. 2007).

Furthermore, the Japanese Census Records, the main source of information on population characteristics in the Japanese context, contain only the information on ‘how many Japanese and non-Japanese live in each areas’. A weakness of this data is that the information related to the non-Japanese population includes integrated data on people from developing and developed nations, and this makes the information pertaining to ethnicity more obscure such that it is difficult to consider the non-Japanese people as socially disadvantaged groups.

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Chapter 3
Environmental equity in a Japanese city: relationship between social indicators and environmental quality

Abstract

In comparison with the US and other countries, there is inadequate knowledge on matters of environmental equity in Japan. By conducting a case study on Yokohama, this research quantitatively investigated the spatial relationship between the socio-demographic characteristics of population and three environmental qualities: proximity to hazardous industrial waste facilities, air pollution exposure, and accessibility to public elementary schools. The results show that higher percentages of blue collar workers (a poverty indicator) were positively related to the proximity to the waste facilities, whereas the percentage of professional and managerial workers (an affluence indicator) decreased with the proximity to the facilities. Communities with more pensioners were likely to be further away from the waste facilities, whereas the percentage of children under 15 years increased with the proximity to the facilities. These results were consistent with the findings of research from the other countries. However, disparities of significant magnitude were not observed for air pollution exposure and school accessibility. This research is one first step for considering environmental equity issues in Japan.

1. Introduction

The achievement of social equity as an outcome of environmental planning and decision making processes is being increasingly recognised as an important component of environmental policies in many countries (Kruize et al. 2007, Pearce et al. 2006). Originally, the concept of environmental equity was developed in the US, being largely driven by racial disparities in environmental quality. Since the 1980s, environmental equity has become a significant issue for the environmental movement (Liu 2001). It was driven by the early findings of researchers such as Zimmerman (1983) who found that waste disposal sites tended to be located in communities whose populations were mostly non-white or poor, resulting in a magnification of risks amongst those population groups. However, more recent work has expanded these concerns to incorporate disparities associated with more varied population characteristics, including age (e.g. Brainard et al. 2002, Christie and Fone 2003). In early works, environmental equity analyses also focused only on consideration of disamenities such as exposure to atmospheric pollution or hazardous facilities, but in recent years access to amenities, such as public parks or healthcare facilities has also been considered (Boone et al. 2009, Christie and Fone 2003). Considering those trends, we adopt the definition of environmental equity as equal protection from environmental risks or equal opportunity to receive good environmental standards according to individual or population socio-demographic characteristics (EPA 1992, Jones et al. 2009a).

Environmental equity studies have been undertaken in many countries including the USA (e.g. Fisher et al. 2006, Saha and Mohai 2005), the UK (e.g. Walker et al. 2005, Comber et al. 2008, Walker and Burningham, 2010, Jones et al. 2009a), Holland (e.g. Kruize et al. 2007), Canada (e.g. Jerrett et al. 2001, Buzzelli et al. 2003), and New Zealand (e.g. Pearce and Kingham 2008, Pearce et al. 2006), yet very little is known about the situation of environmental equity in Japan. There are several important reasons for considering Japan. Firstly, it is a country where problems of poverty, social inequity and an aging society are increasing (Tachibana and Urakawa 2006, Iwata and Nishizawa 2005), and these processes may have particular equity implications. Tachibana and Urakawa (2006) argue that until recently, these issues were not well recognised in the country, which may explain why few have investigated equity issues. Secondly, Serret et al. (2006) raised concerns that, since the majority of environmental equity research has been undertaken in Western nations, it may be that the magnitude of environmental inequities assumed to be prevalent globally are biased according to this predominant geographical source. This research was undertaken therefore to provide new evidence in a very different cultural and environmental setting to that of the USA.

In this case study, the relationships between social indicators and distribution of three environmental qualities are investigated: proximity to hazardous industrial waste management facilities, air pollution exposure, and accessibility of public elementary schools in the Japanese city of Yokohama. This suite thus comprises one environmental amenity and two disamenities.

Waste management facilities were chosen because they have been well studied in other settings. These facilities have the potential to release pollutants into the land and ground water (Kunreuther and Patrick 1991), and several studies found that proximity to them may be related to the risk of congenital malformations (e.g. Geschwind et al. 1992), and also negatively impact the mental health of those living nearby (e.g. Downey and Willigen 2005). Furthermore there is much evidence from other settings that these sites tend to be disproportionately located in non-white or economically deprived communities (Zimmerman 1993, Saha and Mohai 2005, Maantay 2002). In this research, the spatial distribution of waste management facilities for industrial waste requiring special treatment is examined. The definition of special treatment includes waste oil, waste acid, waste alkali, infectious waste, and other specified hazardous industrial waste such as waste PCB, specific sewage sludge, asbestos waste and particulate matter (Ministry of the Environment 2010).

The other environmental disamenity examined in this study is exposure to air pollution. Poor air quality has been consistently related to mortality and morbidity from cardiovascular and respiratory diseases (Samet et al. 2000, Brunekreef and Holgate 2002), and several studies in other countries have reported disparities in air pollution exposure between different population groups. For example, Brainard et al. (2002) reported a significant relationship between poverty, ethnicity and exposure to air pollution in Birmingham, England, and Pearce and Kingham (2008) found that air pollution exposure was disproportionately high in less advantaged New Zealand populations.

The importance of population accessibility to amenities is widely recognized in city planning since access to places that people use regularly is strongly related to quality of life. Accessibility to elementary schools is a significant social issue, and schools are a major factor in determining the residential decisions of families (Gibbons and Machin, 2008). Amongst other factors, good accessibility to schools provides safety for school children (Guntermann and Colwell 1983), and better opportunities for participating in after-school activities that use sports facilities. Nevertheless, relatively few equity studies of equity in accessibility schools have been undertaken. The only notable work is that undertaken by Talen (2001) who found that children with lower socio-economic status had poorest accessibility to schools in rural areas of the US**.**

This study was conducted to test environmental equity of proximity to hazardous waste facilities, air pollution exposure, and elementary school accessibility in Japan, a country where few past environmental equity study is available. After we introduce methodology of equity study of the three environmental qualities, results of statistical analyses is provided. We then conclude by demonstrating the findings, implications and caveats related to our approach.

2. Data and methodology

2.1. Scope of the study

The study area of this research is city of Yokohama, which has the second largest population in

Japan (Figure 3.1). This city is situated in Kanagawa prefecture next to Tokyo, the capital of the country, and the eastern boundary of the city is adjacent to Tokyo bay. Yokohama has been developed around large-scale industries, including manufacturing and tourism. Because Yokohama is a part of the Keihin region, one of the biggest industrial zones in Japan, since the 1940s environmental degradation has been amplified by the growth of industrial facilities, waste management pants or sources of air pollutants, causing much concern (Kanagawa Prefectural Government 2010). The city is known as a dormitory town for Tokyo, and the population increases annually (the total population changed from 2.8 million in 1980 to and 3.6 million in 2005), placing particular demands on the environment.

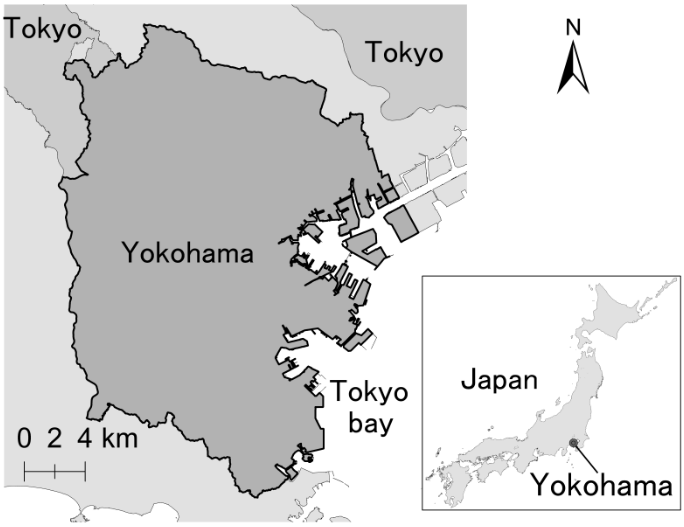

Figure 3.1. Study area (Yokohama)

2.2. Social indicators of population

To define socially disadvantaged groups, we focused on population age and both poverty and affluence levels of communities. All data was extracted from Japanese Census records. Age is an important determinant of vulnerability and life patterns of people (Liu 2001, Sexton et al. 1993). We focused on pensioners (those aged 65 years or more) since this group may be more vulnerable and susceptible to environmental risks (see Filleul et al. 2004, Cakmak et al. 2007) due to their poorer health status and decreased mobility and social activity (Sexton et al. 1993). Young children are also especially vulnerable to environmental risks (Pikhart et al. 1997), and are the group with the need for good accessibility to elementary schools. Thus we also investigated variations in equity associated with the percentage of the population under aged 15. As indicator of poverty, we extracted the percentage of blue colour workers (high poverty) from the census. This group consisted of those classified as ‘manufacturing process workers’ and ‘transport and machine operation workers’. Likewise, to measure the level of affluence in each community, the percentage of ‘professional and technical workers and managers’ (high affluence) was examined.

The social indicators of the population of the study area were extracted from the 2000 (population educational level) and 2005 (population age and job status) Japanese Census at the 500 m census grid cell level (see MIAC 2011). 55 census grids were excluded from the sample because information on population characteristics was classified due to limited number of population.

2.3. Data of three environmental qualities

The distribution of the three chosen environmental qualities in the study area was measured within a Geographical Information System (GIS), and integrated with social indicators from the Japanese census to examine issues of equity. All GIS analyses were implemented using ArcGIS 9.3 (ESRI Inc) using the methodologies described below.

To include positional data on hazardous industrial waste management facilities, facility address lists were obtained from Yokohama City Council. The lists identify each facility address at a building level (the survey year is 2006) which was then mapped in the GIS (Figure 3.2 (a)). To identify the characteristics of the populations proximal to each facility, buffer analysis was used (see Liu 2001). This analysis assumes people living in areas within pre-defined distance as proximate population to facilities, but the appropriate distance to delineate is often not well understood or tested (Maantay 2007). Sheppard et al. (1999) therefore suggest the application of several different buffer distances, and thus 500 m and 1 km buffers were generated here and the census grid cells that fell within them were identified. These distances have been frequently used in past studies (e.g. Sheppard et al. 1999, McMaster et al. 1997). All census areas that were completely or partially enclosed by the buffers were defined as areas that were potentially at risk of contamination from the facilities.

The measure of air quality mapped was the distribution of outdoor nitrogen dioxide (NO_2) concentrations for the year 2005. NO_2 is one of the most prevalent air pollutants in urban areas (Fenger 1999). The main sources of man-made NO_2 are vehicle exhausts, such as those from automobiles and buses, and stationary sources such as industry (Bach 1972). Exposure to NO_2 has been associated with a range of health concerns, and in particular respiratory conditions, and there is evidence that the health effects may be greater amongst more vulnerable members of the population such as the elderly (Fischer et al. 2003) and young children (Pikhart et al. 1997). The data used for this analysis was extracted from the Research Report of Air Pollution published by the Environmental Planning Bureau of Yokohama City Council. In the survey for this report, Yokohama City was divided into 112 2 km x 2 km cells and each cell had an air pollution monitor set in the centre. The concentrations of NO_2 (annual average NO_2, expressed in ppm) at each location were then measured, and for this study the mean NO_2 concentration for each census grid was estimated based on the value of the NO_2 cell that it fell within (Figure 3.2 (b)). NO_2 concentration for 18 census grids close to the city boundary were not available since those areas were excluded from 2 km grid based air pollution monitoring, and these were set to missing data.

The locations of most of public elementary schools were extracted from the Digital Map 2500 (Spatial Data Framework) product published by the Geographical Information Authority of Japan. The scale of this data was 1 / 2500, and survey year was 2005. A small number of schools were not represented on the Digital Map 2500 product and these were identified from a list of municipal schools obtained from Yokohama City Board of Education. Their locations were then identified on paper maps and manually added to the GIS.

In cases where schools had more than two buildings, a point in the centre of the school campus was identified. The resultant locations are shown in Figure 3.2 (a). To compute the accessibility of each school to each 500 m census grid, the road distance between the centre of each census grid and the nearest school point was computed in the GIS (see Talen 2003) using a digital representation of the Yokahama road network also contained within the Digital Map 2500 product.

2.4. Analysis

The relationships between the three measures of environmental quality and each of the socio-demographic characteristics were investigated by classifying census areas into quartiles based on each indicator, and examining how the three measures varied across the quartiles. A set of logistic regression analysis were firstly fitted where the odds of being located within certain distance from waste facilities for each quartile. Next, average values of NO_2 concentration and measures of school accessibility across quartiles were computed. Finally, tests of trend among the quartiles were examined for all of the three analyses. All statistical analyses were undertaken in SPSS 16.0 (SPSS Inc).

3. Results

Figure 3.2 maps the spatial distribution of hazardous industrial waste management facilities**,** air pollution, public elementary schools, and social indicators of population in the study area. Four of the waste management facilities are located in the northeastern part of the city where the Keihin industrial region is situated. The highest concentrations of NO_2 are also observed in this area. The public elementary schools are more uniformly distributed throughout the city.

Table 3.1 reports the results from the environmental equity analysis. Where inequities were apparent their magnitude was generally greater for the 500 m buffer suggesting this distance may be most sensitive for equity analyses measuring associations with population characteristics. The trend in odds ratios shows that communities with more retired residents are likely to be further away from the industrial waste facilities. However, the percentage of the population aged 15 increased with proximity to waste facilities, although only for the 500 m buffer. Stronger evidence of inequity was apparent for blue collar workers, with more impoverished communities with high percentage of them being more likely to be located within the buffers. As may be anticipated, the opposite association with proximity was apparent for the percentage of professional and managerial workers in census grid cells.

Magnitudes in the variation of NO_2 exposure across the different social groups were very small although areas with the highest percentages of retired populations and children did experience slightly lower concentrations of pollution. Surprisingly the percentage of the population aged under 15 showed no association with distance to elementary schools. As schools are not needed by retired populations, accessibility was not tested in this group. The results do suggest however that communities with a high percentage of blue collar workers tend to have worse accessibility to public elementary schools, although magnitude of inequity was again small across quartiles.

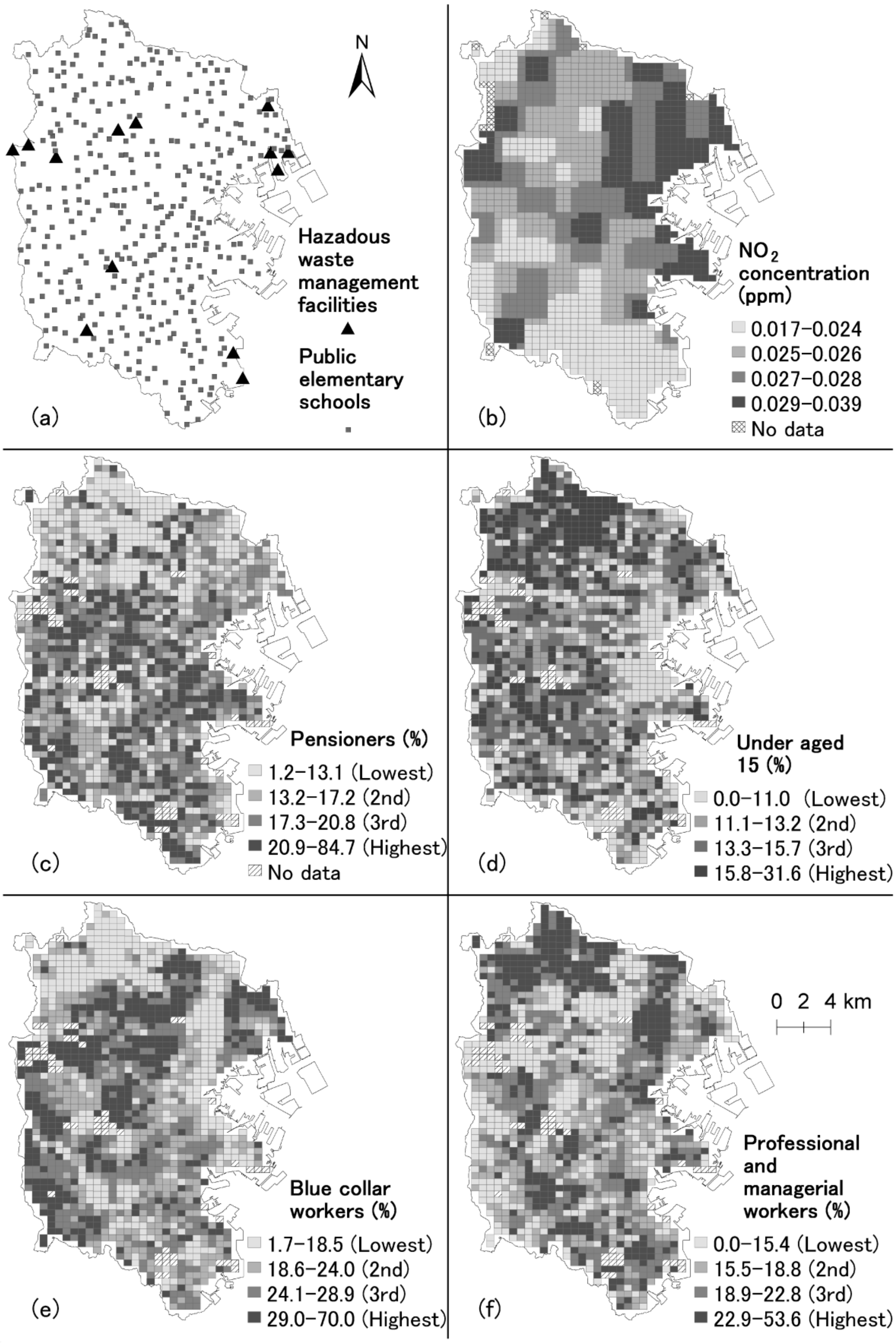

Figure 3.2. Spatial distributions of (a) hazardous industrial waste management facilities and public elementary schools; (b) NO_2 concentrations; (c) pensioners (%); (d) those aged under 15 (%); (e) blue collar workers (%); and (f) professional and managerial workers (%)

Table 3.1. Result of environmental equity analysis.

Quartiles	500 m buffer from waste facility				1 km buffer from waste facility				NO_2	Distance to
	Within	Outside	OR	95% CI	Within	Outside	OR	95% CI	(ppm)	school (m)
Pensioners (%)										
Lowest	28	312	1		49	291	1		0.0265	
2nd	7	333	0.23	0.10-0.54	33	307	0.64	0.40-1.02	0.0266	
3rd	14	326	0.48	0.25-0.93	34	306	0.66	0.41-1.05	0.0266	
Highest	3	337	0.10	0.03-0.33	9	331	0.16	0.08-0.33	0.0256	
Trend			—**				—**		—**	
Under 15 (%)										
Lowest	8	333	1		29	312	1		0.0266	690
2nd	9	330	1.14	0.43-2.98	22	317	0.75	0.42-1.33	0.0262	689
3rd	17	323	2.19	0.93-5.15	41	299	1.48	0.89-2.44	0.0263	669
Highest	18	322	2.33	0.99-5.43	33	307	1.16	0.69-1.95	0.0261	705
Trend			+*				+ NS		—*	+ NS
Blue collar workers (%)										
Lowest	3	337	1		11	329	1		0.0267	663
2nd	6	336	2.01	0.50-8.09	19	323	1.76	0.82-3.76	0.0261	654
3rd	10	328	3.42	0.93-12.56	33	305	3.24	1.61-6.52	0.0259	697
Highest	33	307	12.07	3.67-39.77	62	278	6.67	3.44-12.92	0.0266	739
Trend			+**				+**		—NS	+**
Professional and managerial workers (%)										
Lowest	26	314	5.55	2.10-14.63	50	290	3.28	1.85-5.81	0.0265	722
2nd	13	327	2.66	0.94-7.56	34	306	2.11	1.16-3.86	0.0265	692
3rd	8	332	1.61	0.52-4.99	24	316	1.44	0.76-2.74	0.0261	659
Highest	5	335	1		17	323	1		0.0261	680
Trend			—**				—**		—NS	—NS

Lowest / highest Quartile = Least / most percentage of population characteristics
Within = number of census grid within buffer of hazardous waste facilities
Outside = number of census grid outside buffer of hazardous waste facilities
OR = Odds ratio 95%CI = 95% confidential interval
Direction of trend (+ positive – negative)
**: $P < 0.01$ *: $P < 0.05$ NS: No statistical significance

4. Discussion and conclusion

Since very little is known about environmental equity in Japan, this research was conducted to test existence of inequity. Applying cross-sectional modeling of distribution of the three environmental quality metrics, this research provided some evidence of inequities in Yokohama, Japan. This was particularly so for the association between each job status and proximity to waste facilities. These results support findings in other countries, such as the US, where often found disproportionate burden of environmental risk in socially disadvantaged communities (for example, see Zimmerman 1993, Sheppard et al. 1999). However, we also found that a high percentage of the elderly residents was negatively associated with proximity to facilities. No inequities in air pollution exposure and school accessibility of any notable magnitude were observed between different social groups.

Despite of the strong evidence of inequity of proximity to waste facilities, it is important to remember that blue collar workers living nearby the facilities may enjoy other benefits which offset their poorer living environment, the most obvious being good access to workplaces in industrial areas.

There are several limitations to our study. The fact that our design was cross sectional means that it provides no information on the causal mechanisms that may underlie and inequity observed. Longitudinal studies which focus on time-dependent changes in environmental equity are needed for this (Saha and Mohai 2005), and indeed several previous longitudinal studies identified that unequal distributions of political power between communities and problems with market mechanisms may be important. Pastor et al. (2001) suggested that poorer populations are disadvantaged because they lack the resources to resist the siting of environmental disamenities. If this is the case in Yokohama, careful re-examination of zoning laws and encouragement of public participation for socially disadvantaged populations may help. In addition Been (1994) found that lower housings cost in environmentally disadvantaged areas attracts disadvantaged populations via move-in. If this is so then income redistribution programs, such as the provision of rent assistance for disadvantaged groups, may also have a play to role (ibid).

Our analysis was based on residential location, and migration patterns were not incorporated. In reality, people often move outside their home neighbourhoods for work, recreation or other purposes, and may thus experience different environmental risks or opportunities (Brainard et al. 2002). In the future it may be feasible to incorporate global positioning systems (GPS) into population surveys to capture people’s travel patterns and incorporate them into framework of environmental equity studies (Jones et al. 2009b). A further consideration is that the buffer approach we employed is a simplified method for calculating environmental associations as this approach assumes that the people within the buffer face an equal amount of risk or benefit (Maantay 2007). In reality patterns of exposure to of environmental and benefits will vary on a more continuous scale, being related to factors such as wind and water flow direction, topographical characteristics and other environmental factors. (Boone 2008, Liu 2001). Nevertheless, the extent to which distance from the facilities is related to the actual risk or exposure of a neighbourhood is yet to be determined (Maantay 2007), and the sensitivity analysis we undertook suggests that a 500 m buffer my represent a sutable distance for detecting associations.

A further limitation is that our measure of access to schools did not consider quality. Student performance is often used as a measure of quality (Clapp et al. 2008), but information on test scores across public elementary schools was not available for the sample area. Moreover, these score can themselves be associated with population demographic characteristics (Gibson and Asthana 1998) in ways in which the direction of causality is unclear. Therefore we suggest quality is difficult to measure in an equity context.

Although the study area of this research is small, Yokohama is a well-known Japanese city situated next to the capital Tokyo, and hence this city could easily be considered a typical Japanese urban area in terms of geography, population and reputation. We found strong evidence of inequity in proximity to hazardous waste facilities in the city. Further work is needed to test this association either at the national level or in other Japanese settings, and future research should be expanded to cover a wide spectrum of environmental amenities and disamenities.

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Chapter 4
Environmental equity of park accessibility in Japan: the role of park providers and market mechanisms

Abstract

Despite an increasing interest in issues surrounding environmental equity, much research evidence to date is based on studies adopting cross-sectional approaches which do not adequately capture the processes and mechanisms generating inequities. Longitudinal studies may better inform policy measures to remedy inequity between populations, but the few that have been undertaken mostly focus solely on environmental risks, ignoring access to amenities. As a case study, we adopt a longitudinal approach in this work to investigate the association between socio-demographic indicators and public park provision over an 18 year period in the city of Yokohama, Japan. We show that inequities in park provision are present over the whole time period. Hedonic modelling shows that park accessibility is positively associated with house and land prices in the city. Our results suggested some, relatively weak, evidence of two causal processes; new parks are located in more affluent communities, yet also appear to subsequently encourage further move-in of affluent populations. We suggest direct park provision by administrative authorities in less affluent neighbourhoods may be required to maintain equity in access to these valuable community resources.

1. Introduction

In recent decades, there has been an increasing interest in issues surrounding environmental equity. The concept of environmental equity particularly grew from action against environmental racism in the 1980s in the USA (Liu 2001), with a distinct focus on the siting of controversial facilities such as hazardous waste dumps in areas occupied by non-white populations (e.g. GAO 1983, Godsil 1991). Since then the equity movement has based its efforts on the goal of achieving planning outcomes that leads to an equal sharing of environmental hazards and opportunities (EPA 1992, Jones et al. 2009). Nevertheless recent findings in a range of international settings suggests that inequities often still persist and are associated with diverse factors including age, ethnicity and affluence (e.g. Fisher et al. 2006, Kruize et al. 2007, Pearce et al. 2006, Mitchell 2005, Comber et al. 2008, Jones et al. 2009).

It has identified that studies in the environmental equity field use mostly one of two methods (Mohai 2008, Nichols 2001, Mitchell 2005). The first is cross-sectional investigations of the distribution of environmental quality between different population groups (e.g. Fisher et al. 2006, Nichols 2001). Whilst this is the most common approach, these cross-sectional studies are based on observations made at a single time point, generally focus on only one outcome, and hence they do not adequately capture the causes and processes generating environmental inequities. An alternative is to take a longitudinal approach which focuses on time-dependent changes in the relationship between environmental qualities and population characteristics.

In longitudinal studies the question of ‘Which came first?’ is frequently asked (Boone et al. 2009, Mohai 2008, Pastor et al. 2001). The concept being considered here is that environmental inequity may be generated through two different processes. The first is that environmental risks come into already socially disadvantaged communities or benefits tend to be sited in affluent areas. The second is that disadvantaged or advantaged groups move into areas after the placement of environmental disamenities or amenities. Those two different processes can be caused principally by two factors; unequal political power between communities and market mechanisms (Pastor et al. 2001), both of which may be in operation and may be complementary to each other (Saha and Mohai 2005).

To support the argument of the first process, it has been suggested that disadvantaged groups have limited political power to resist the disproportionate siting of disamenities, and thus their areas attract more environmental risks (see Pastor et al. 2001, Hamilton 1993 and Hamilton 1995). Conversely, more affluent or socially advantaged communities may be more politically empowered to attract new environmental amenities such as parks (Boone et al. 2009, Talen 1998). Market mechanisms are the other potential driver of disproportionate siting since developers or authorities may chose socially disadvantaged areas to site controversial facilities due to cheaper land prices and less need to provide compensation for local people (Portney 1991, Hamilton 2006). For amenity siting, however, market mechanisms may actually sometimes be beneficial for the socially disadvantaged since cheaper land prices may encourage new amenity siting by providers, particularly for developers who have an obligation to provide amenities but where there is some flexibility on their location.

It has also been suggested that disadvantaged populations may actually be attracted into environmentally disadvantaged neighbourhoods by low property prices (see Been 1994, Saha and Mohai 2005), or partly by housing discrimination practices such as the limited provision of social housing (Nakagawa 2001, Choi et al. 2005). Conversely, the affluent may be attracted into areas with good amenities (Jones et al. 2009, Boone et al. 2009). If these processes do exist, policy makers may face a problem as policies attempting to more evenly distribute environmental quality may backfire if consequent changes in land and property prices cause people to reallocate, resulting in the re-occurrence of inequity (Liu 2001).

Although several longitudinal studies have been undertaken to clarify the process of equity in the burden of environmental risks (e.g. Been 1994, Saha and Mohai 2005, Oakes et al. 1996, Pastor et al. 2001, Hamilton 1993, Been and Gupta 1997, Hamilton 1995), very little is known about the distribution of amenities. In this research we examine the potential existence of the mechanisms discussed, and what the potential policy implications of their presence may be. As a case study, we focus on the longitudinal association between the siting of an environmental amenity, public parks, and social-demographic characteristics in Yokohama, Japan, a country where rather little work on environmental equity has been undertaken.

Parks are increasingly being recognised as an important component of the urban landscape. There is good evidence that they positively affect people's physical health, providing opportunities for recreation and physical activity (Payne et al. 1998) and more generally contributing to the psychological and social health of communities (Gies 2006 and Hirata 2004). Moreover large green spaces mitigate the effect of air and noise pollution (Gies 2006 and Hirata 2004). Proximity to open spaces including parks is also expected to play a vital role for natural hazard management and protection against earthquakes and fires (Koike et al. 2010 and Ishikawa, 2006). However there is some evidence in international settings that the provision of parks may be inequitable. Jones et al. (2009) examined the distribution of access to parks between populations in Birmingham, England, and found evidence of disparities in provision related to socioeconomic deprivation, whilst Wolch et al. (2002) and Sister et al. (2007) both found that communities with Latinos, non-white or low income groups have worse access to parks in American contexts.

This case study of Yokohama was made to describe an approach to the longitudinal modelling of park provision. We examine both siting and move-in hypothesises presented above. In order to investigate the potential causal role of market mechanisms, we then present a hedonic model which quantifies the association between park provision and land and property price changes.

Hedonic pricing considers a land parcel or a property as a set of attributes, against which its price is modelled (Hidano 2002, Rosen 1974). Our hedonic models focus park provision as the key attribute of interest. We conclude by presenting the strengths and caveats associated with our approach, as well as the potential policy implications of our findings.

2. Methodology

2.1. Study areas

The area used in this case study is Yokohama, Japan, which is located in Kanagawa Prefecture and bounded by Tokyo Bay and Tokyo, the Japanese capital (Figure 4.1). Yokohama has the second largest population in the country, and is a significant economic base for manufacturing, tourism and shipping. The city is undergoing significant population growth and it acts as a dormitory town for many people who work in the nearby Tokyo.

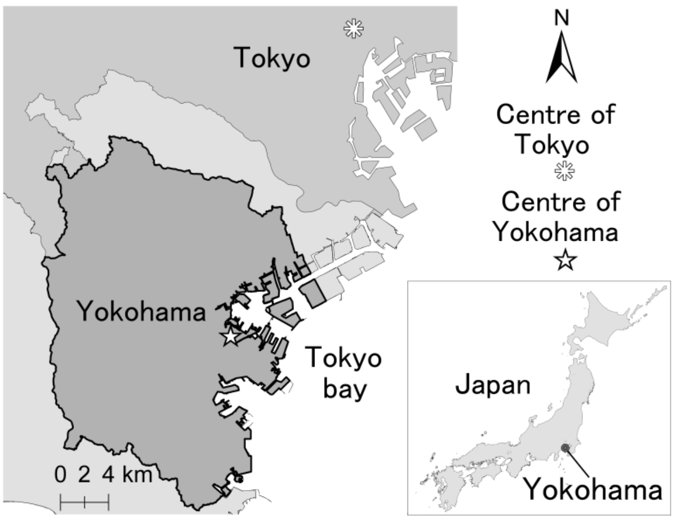

Figure 4.1. Study area (city of Yokohama)

2.2 Data

For the purpose of this study, two main datasets were generated; a 1 km grid based on census derived population characteristics, and a set of digital maps of park provision in Yokohama. Both were computed for a range of time points.

The census data was extracted from the Population Census Grid Square Statistics published by the Ministry of Internal Affairs and Communications (MIAC 2011). The census is conducted every five years, and for this study, the results of surveys conducted in 1990, 1995, 2000 and

2005 were employed. This analysis focussed on two socio-demographic indicators. The first was the percentage of pensioners in grid cells, defined as individuals aged 65 years or older. The elderly are often regarded as a socially disadvantaged group, due to their poorer health, and reduced mobility and social activity (Sexton et al. 1993). Since our research interest is whether socially advantaged communities attract park provision, or advantaged people move into areas after the siting of parks, we also extracted the percentage of professional and managerial workers as an indicator of population affluence for each cell. Ten 1 km grids were however excluded from the samples since their information on population characteristics were not released due to their small population.

To measure accessibility to public parks for each 1 km census grid, we firstly generated maps of parks within the ArcGIS 9.3 (ESRI Inc.) Geographical Information System (GIS). A database of urban parks was obtained from Yokohama City Council, supplying information on the name, address, park area, and the opening year of each park located within the city. For the purposes of map production, we differentiated parks which were larger than 2 ha in area from those which were less. For the larger parks, we depicted the park boundaries on our map using outlines present in the 2005 edition of the ‘Digital Map 2500’ (1:2500) digital cartographic product produced by the Japanese Geographical Survey Institute. Manual checking of Digital Map 2500 highlighted a number of parks which were not present, and the boundaries of these were subsequently digitised from a local paper atlas. Small parks of less than 2 ha in area were represented as circles with an area equal to that of the corresponding park. The circles were located using address-matched latitude and longitude coordinates from on-line lookup tables produced by the Centre for Spatial Information Science at the University of Tokyo (CSIS 2011).

Using the information on park opening dates held in the database, the mapping procedure was repeated 18 times to produce a map of park locations for every year between 1988 and 2005, the most recent period for which data was available. The maps were additive because no park was recorded as being closed during this period. The city of Yokohama also provided information on whether each park was opened by a private developer or the city council, and this was added to the database. For each 1km grid cell for which census data was available, access to parks was measured using four metrics; firstly the number of parks within the cell, secondly the park area, and thirdly the park area per capita. The computation of these metrics is known as the ‘container’ method (see Talen and Anselin 1998). The fourth metric was whether or not a park was opened in a given year. Parks provided by the city council and by private developers were differentiated in these metrics. The two park providers were considered separately due to the different policies governing them. City council parks are specified to be located in areas where provision is not already good (Hirata 2004), whilst if an area of a planned new development plan is more than 5 ha, legislation requires that 3% of the developed area has to be public park provided by developers.

A range of covariates which were hypothesised to potentially to be associated with park provision were considered (Table 4.1). The two population characteristics of interest, percentage pensioners and percentage professional and managerial workers, were computed from census records and classified into quartile groups. Population density was also computed based on census records since highly populated areas may have more demand for parks. However, since the Japanese census data is collected every five years, it is not possible to model annual changes in population characteristics against annual changes in park provision. Therefore, we took a time-period based approach and examined the changes in population characteristics at a time which was as temporally coincident as possible to that of park provision (see Saha and Mohai 2005).

As new park provision may depend on existing provision, the number of parks that were already present within each 1 km grid was extracted from the previously described park database. Cheaper land prices may attract park provision, and hence in order to include a consideration of land prices in the analysis, estimated land values that are annually published by the Ministry of Land, Infrastructure, Transport and Tourism were considered. This data consists of point based estimates; for example, there were around 900 estimation points in 2005, and each point represents a specific estimated land price produced by professional assessors (see Hidano 2002). In order to estimate land prices for each grid cell, we created Thiessen polygons (Johnston 1998) for each year based on the locations of the points whose land price data was estimated, and these were overlaid with the grid cell boundaries to estimate the average land price within each cell.

Private developers may be more likely to develop land close to city centres. Therefore, to determine the level of accessibility to the centres of Yokohama and Tokyo (the capital city of Japan), we calculated the Euclidean distance from the each centroid point of 1 km grid to the centres of both cities using ArcGIS.

Table 4.1. Explanatory variables for the siting analysis, move-in analysis and hedonic analysis

Variable	Reference source	Hypothesised relationship	Data source	Descriptive statistics Min	Mean	Max	SD
Variables for the move-in analysis (logistic regression)							
Quartile groups of pensioners (%)		DEV: NS CC: NS	Census	-	-	-	-
Quartile groups of professional & managerial workers (%)	Robinson & Robinson (1985)	DEV: + CC: NS	Census	-	-	-	-
Population density (people/km^2)		DEV: NS CC: +	Census	13	8612	22162	4564
Number of parks pre-existing	ibid	DEV: + CC:－	DM, MP	0	5.9	22	3.8
Estimated land price (100,00 yen)		DEV:－ CC:－	ELP	9.8	41.2	773.4	50.6
Distance to Yokohama centre (km)		DEV:－ CC: NS	DM	0.4	9.7	19.8	3.9
Distance to Tokyo centre (km)		DEV:－ CC: NS	DM	17	29.1	41	6.2
Variables for the move-in analysis (multiple regression)							
Park provision by developers	Jones et al. (2009)	PEN: － P&M: +	DM, MP	-	-	-	-
Park provision by city council	ibid	PEN: － P&M: +	DM, MP	-	-	-	-
Population density (people/km^2)		PEN: － P&M: －	Census	13	8612	22162	4564
Distance to Yokohama centre (km)		PEN: －P&M: －	DM	0.4	9.7	19.8	3.9
Distance to Tokyo centre (km)		PEN: －P&M: －	DM	17	29.1	41	6.2
Quartiles of pre-existing pensioners (%)		PEN: +	Census	-	-	-	-
Quartiles of pre-existing profess -ional & managerial workers (%)		P&M: +	Census	-	-	-	-
Quartiles of park area pre-existing		variable	DM, MP	-	-	-	-
Variables for the hedonic analysis							
Structural variables							
Ground area (m^2)		+	RIW	13.8	136.6	991.7	64.9
Floor space (m^2) (detached house only)		+	RIW	0	80.1	1840.4	45.3
Width of front road (m)	Shimizu (2004)	+	RIW	0	5.4	45.0	2.5
Private road dummy	ibid	－	RIW	-	-	-	-
Residential zoning dummy		+	RIW	-	-	-	-
South-facing dummy	Gao & Asami (2001)	+	RIW	-	-	-	-
Reinforced concrete dummy (detached house only)	Shimizu (2004)	+	RIW	-	-	-	-

Table 4.1. (continued)

Neighbourhood variables							
Professional & managerial workers (%)	Shimizu (2009)	+	Census	0	5.2	22.0	3.9
Population density (people/km^2)		variable	Census	6	8407	25859	4736
Accessibility variables							
Distance to Yokohama centre (km)	Hidano (2002)	—	DM	0.4	9.4	20.3	4.3
Distance to Tokyo centre (km)	ibid	—	DM	16.2	29.1	42.0	6.0
Distance to elementary school (km)	Pacione (1989)	—	DM, SL	0	0.4	1.4	0.2
Travel time to closest rail station (min)	Shimizu (2009)	—	RIW	0	12.6	38.0	4.9
Using bus dummy	ibid	—	RIW	-	-	-	-
Environmental variables							
Quartile groups of park area		+	DM, MP	-	-	-	-
Variables related to transaction							
Year 2000 dummy		—	RIW	-	-	-	-
Year 2005 dummy		—	RIW	-	-	-	-
Market reservation time (month)	ibid	variable	RIW	0	2.6	50.4	2.6

Hypothesized relationship with dependent variables: DEV - developers; CC - city council; PEN - temporal change in pensioners (%); P&M - temporal change in professional and managerial workers (%)

Positive relationship (+) and; negative relationship (—); and no statistically significant relationship (NS)

Key to reference and data source: RIW - Residential Information Weekly; Census - Japan Census (Tabulation for 1 km grid) in 1990, 1995, 2000 and 2005; DM - Digital Map 2500; SL - Yokohama Municipal School List of Names; and MP - Map of Parks and Green Spaces in Yokohama

In order to examine the move-in hypothesis, we investigated the association between park provision and temporal changes in two demographic characteristics: the absolute change in percentage of pensioners and of professional and managerial workers between two different points of time.

Again, we differentiated between parks provided by the city council and those from developers. Another potential factor influencing population change could be the percentage of the given population already existing in the year of siting of parks, because a predominant population may attract more of the same owing to the similar residential preferences, life patterns, or, partly, the effects of housing discrimination (Nakagawa 2001). Therefore, quartiles of the percentage of pensioners and of the percentage of professional and managerial workers at baseline were computed. Furthermore, if a community already has a large number of parks or a large park area, an additional park may have little effect. Therefore, to differentiate between the potential effect of pre-existing parks and that of a newly opened park, we also incorporated the park area at baseline into our analysis.

For our hedonic pricing analysis, data on the prices of land parcels and detached houses in Yokohama was extracted from the *Residential Information Weekly* publication (RECRUIT., CO.). This weekly magazine describes the characteristics and asking prices of both residential properties and plots of land. Although only 40% of Yokohama residents live in detached houses, data on rents of apartments are unfortunately not published. It was assumed that the price recorded when the property or land was removed from the magazine (normally at the point of sale) was the actual transaction price, an assumption that previous empirical research has tested and found to be appropriate (Shimizu 2004). The two metrics chosen were selected to measure the current (house prices) and future (land prices) potential of areas for move-in.

We used land and detached house price data from three survey years; 1995, 2000, and 2005. The address of each transaction point was converted into a latitude and longitude and the location points were recorded in the GIS. Figure 4.2 illustrates the location of transaction points of land parcels and detached houses in 2005.

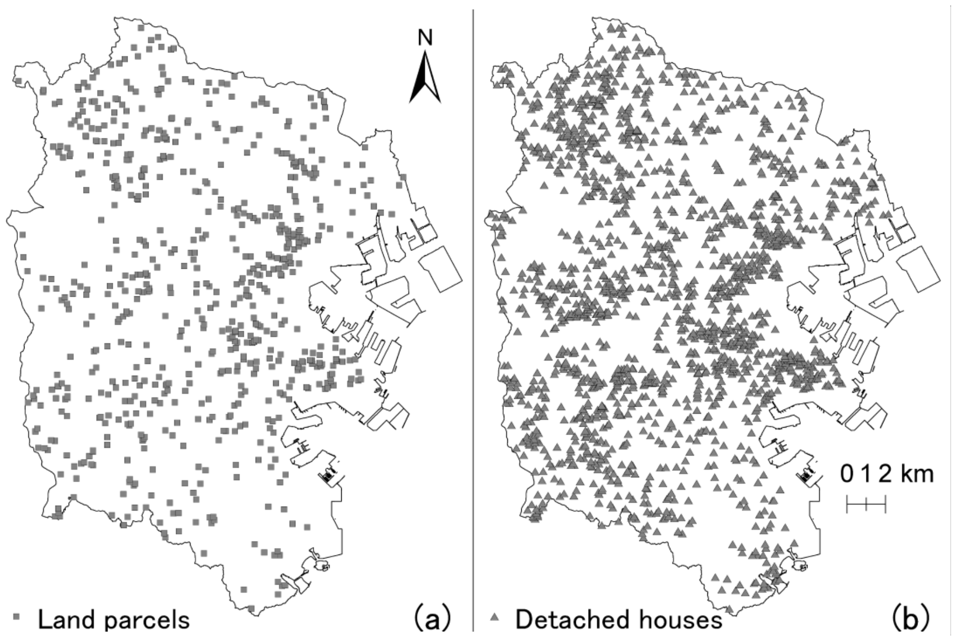

Figure 4.2. Locations of transaction of (a) land parcels and (b) detached houses in 2005

Although the focus of this analysis was on the association between market prices and park provision, it was important to control for all factors that may influence both. Bateman et al. (2001) suggested that there are four major groups of relevance; structural, neighbourhood, accessibility, and environmental variables. Structural variables are characteristics of pieces of land and the houses themselves, such as floor space and the width of the road in front of the building. Neighbourhood variables (e.g. population density) are characteristics of neighbourhoods that will influence desirability. Accessibility variables are indicators of the ease by which local amenities (e.g. distances to rail stations and schools) may be reached, whilst environmental variables encompass measures of the quality of surrounding environment, such as availability of parks.

The suite of variables generated is listed in Table 4.1. In terms of structural characteristics, those computed were measures of ground area, floor space (for detached houses only), the width of the road in front of the property, whether the road is private or public, whether the parcel or property falls inside a zone which is designated for residential purposes, whether the entrance of the land parcel or property is south-facing (for good access to sunlight), and if the house is constructed from reinforced concrete and hence valued due to better earthquake resistance (Shimizu and Karato 2007) were computed.

A series of neighbourhood variables were generated from the Population Census Grid Square dataset for the years 1995, 2000 and 2005. As no readily accepted index of deprivation exists in Japan, the percentage of professional and managerial workers was used a measure of area affluence, and the population density was used to capture the level of crowding. In order to capture elements of accessibility, we created a set of variables which measured the proximity of each transaction point to the city centres of both Yokohama and Tokyo, closest public elementary schools, and closest railway stations.

Accessibility to the centres of Yokohama and Tokyo as well as elementary schools were computed based on Euclidean distances in the GIS. Railway accessibility was measured considering the time required to walk to the nearest bus stop and then make a bus journey to the nearest railway station, except in cases where it was faster to directly walk to the station, where only the walking time was considered. As distances would differ by mode, a dummy variable representing a bus journey was defined, and then the cross term between it and travel time was fitted.

The key environmental variable studied, and the exposure of interest in this part of the study, was the accessibility of parks. To compute this, the same 'container' method as described earlier was employed, this time using a 500 m circular distance buffer. This distance was chosen because, in a Japanese context, Aoyama and Kondo (1986) found that the propensity to visit parks declined steeply amongst populations living further than this distance away. Using the GIS we identified public parks that fell both partially and completely within each buffer, and then summed the total area of each park. Each transaction point was then classified according to the quartile of park area that fell within the buffer.

As the transaction dataset was collected for three time periods, dummy variables for the survey years were fitted into the equations to adjust effect of change in prices over time. Finally, the market reservation time was also recorded, because properties or land parcels that had been on the market for a long time might have been so because their original selling prices were largely unmatched with the market equilibrium price or because they were a unique type of property (Shimizu 2009), such as one designed for handicapped people.

2.4. Analytical methodology

Descriptive statistics and tests for trend were initially used to examine how park access varied by population characteristics over the time periods analysed. For tests for trend, Spearman's rank-order correlation analysis was undertaken to clarify the association between quartiles of each population characteristics and the number of parks, the park area, and park area per capita within the census grid cells.

Next, to test the siting hypothesis, logistic regression analysis was conducted to examine how population characteristics of each community were associated with park provision in each year over the 18 year-time timescale adopted. The 1990 census record was considered to examine the effect of population characteristics on park provision between 1988 and 1992. Likewise population characteristics extracted from the 1995 census data were used to test the park provision between 1993 and 1997, the 2000 census was used for the park siting between 1998 and 2002, and finally the 2005 census was considered for the park siting between 2003 and 2005.

In order to test the move-in hypothesis, multiple regression models were developed to test how park provision was associated change in population characteristics in each census grid. As there would be expected to be a lag time between park provision and population change, and the nature of that lag is not known, we observed three different spans. First, we examined how changes in census characteristics between 1990 and 2005 were associated with park provision between 1988 and 1992. Similarly, we related population change between 1995 and 2005 to park provision between 1993 and 1997, and population change from 2000 to 2005 to parks built between 1998 and 2002.

Two hedonic pricing models, a land price model and a detached house price model, were fitted to identify how additional park accessibility potentially affects both land and property prices. Based on the work of Doguchi and Kubo (2006), these models took the form:

$$\ln P_t = \alpha + \beta_{it} X_{it} + \delta_t d_t + \varepsilon_t$$

Where P_t is the land price i or property price i, α is the intercept, X_{it} is the matrix of independent variables and β_{it} is the vector of parameters to be examined. δ_t indicates to what extent prices change over time when all other variables are controlled. d_t is a dummy variable of time, and ε_t is an error term. All analyses were undertaken in PASW statistics 18.

3. Results

Figure 4.3 illustrates spatial distributions of parks and population characteristics in 1990 and 2005. In 1990, as Figure 4.3 (c) shows, most of aged communities were concentrated around the city centre, but by 2005 those communities had spread towards southern-west parts. Moreover, percentage of pensioners of the population who were pensioners doubled between 1990 and 2005. In both periods, areas with high percentage of professional and managerial workers are situated in northern part of Yokohama, reflecting at least partially the role of the city as a dormitory town of Tokyo.

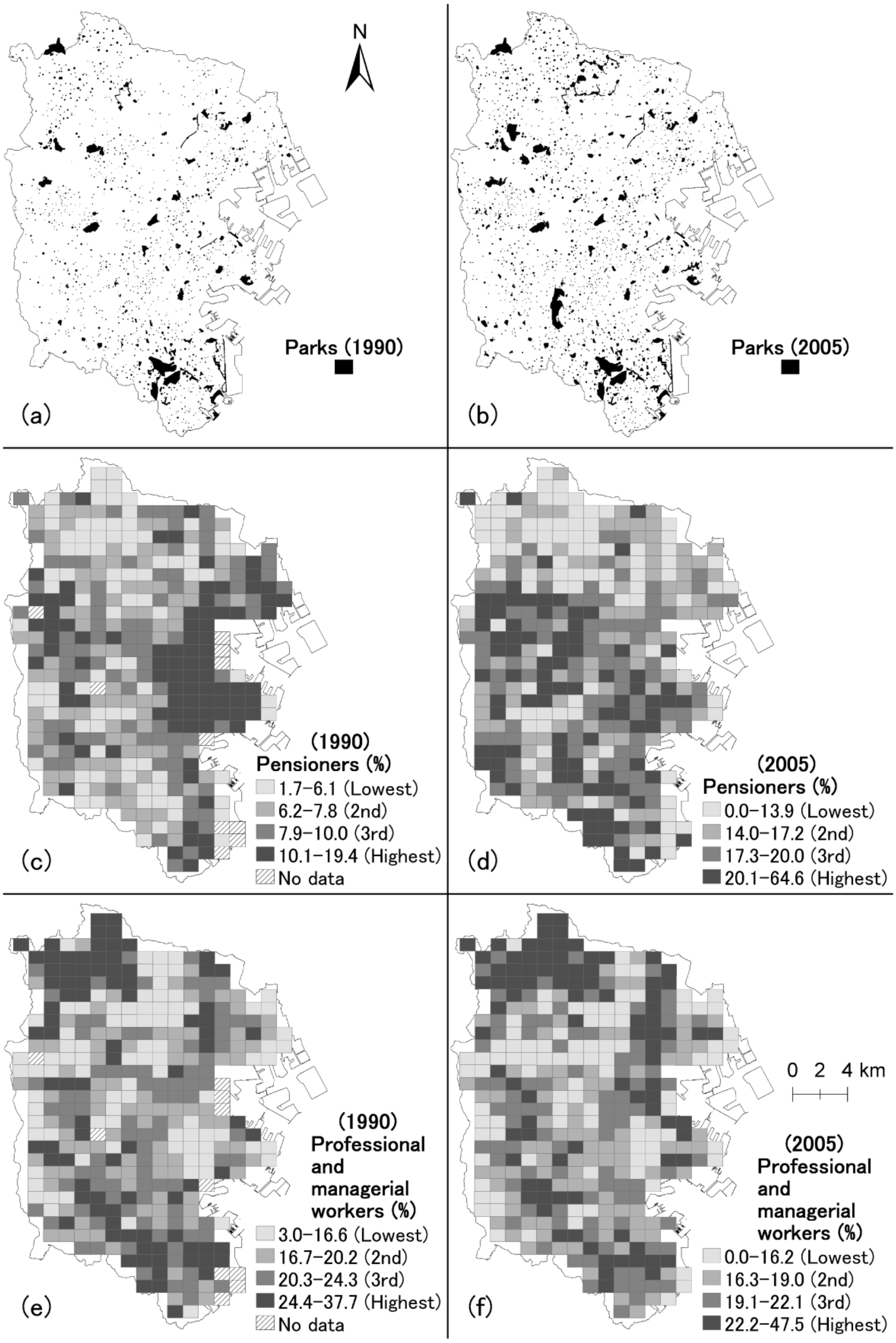

Figure 4.3. Spatial distributions of (a) public parks in 1990; (b) public parks in 2005; (c) pensioners (%) in 1990; (d) pensioners (%) in 2005; (e) professional and managerial workers (%) in 1990; and (f) professional and managerial workers (%) in 2005

Between 1988 and 2005, the city council opened 556 parks (total park area 1702 ha), whilst developers provided 472 parks, but an area of only 212 ha. This suggests that parks built by developers are likely to be smaller than ones provided by the city authority. Areas categorised into the most aged communities (census grids in the top quartile of percentage pensioners) were provided 95 parks by developers with a total area of 18 ha, whereas developers constructed 105 of 117 ha parks in the least aged communities (lowest quartile). For the same period, developers opened 125 parks (117 ha) in the most affluent communities, while in the least affluent communities only 59 parks (20 ha) were provided. Unequal siting of parks by the city authority for the 18 years was not observed.

Table 4.2 shows associations between park accessibility and quartiles of the two demographic groups in Yokohama for the years 1990, 1995, 2000 and 2005. There was no evidence of any trends in inequity associated with the percentage of pensioners at any time period, but there was evidence of inequity in access to parks associated with the percentage of professional and managerial workers, with the most affluent areas tending to have access to parks in all time periods. The trend is particularly apparent when the overall area of parks is considered. However, the mean value of the park area per capita shows a less clear trend, partly due to some census grids have small populations but large park areas and consequently high per capita values. The median per capita values are thus more reliable.

Table 2. Relationship between demographic indicators and park area at different time points (1990, 1995, 2000 and 2005)

		Pensioners (%)						Professional and managerial workers (%)					
		Number of parks		Park area (ha)		Park area per capita (m^2)		Number of parks		Park area (ha)		Park area per capita (m^2)	
	Quartiles of demographic indicator	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median
1990	Lowest	4.5	4	11.5	2.0	114.4	2.6	2.7	2	4.8	0.4	110.6	0.9
	2nd	4.7	4	8.4	1.4	25.4	1.8	4.5	4	8.1	1.8	12.3	1.8
	3rd	4.8	4	8.6	1.2	14.7	1.6	5.7	6	10.1	1.5	31.3	2.2
	Highest	5.1	4.5	9.1	3.0	48.9	2.3	5.9	6	13.8	2.5	53.9	3.0
	Test for trend	+		+		—		+**		+**		+**	
1995	Lowest	5.3	5	10.9	3.0	86.9	4.1	3.3	2	4.9	0.6	29.1	1.4
	2nd	5.4	5	7.6	2.3	15.8	2.8	5.8	5	9.5	3.2	73.8	3.1
	3rd	5.8	5	13.7	2.3	90.9	2.8	6.6	7	10.5	2.3	35.9	2.4
	Highest	6.2	5	9.9	3.4	24.8	2.6	6.6	7	16.4	3.7	77.1	4.2
	Test for trend	+		+		—		+**		+**		+**	
2000	Lowest	6.2	6	11.6	3.6	62.3	5.2	3.9	3.5	9.3	2.0	393.1	2.6
	2nd	6.1	5	10.1	2.4	61.6	2.8	6.8	6.5	11.3	3.5	32.0	3.8
	3rd	7.0	7	13.3	3.4	21.5	3.5	7.8	8	12.2	3.3	43.2	3.0
	Highest	6.9	6.5	16.2	4.9	352.1	4.6	7.0	7	17.7	4.8	83.9	5.1
	Test for trend	+		+		—		+**		+**		+**	
2005	Lowest	6.7	7	13.8	4.3	282.3	5.0	4.7	4	10.9	2.6	286.5	3.3
	2nd	6.9	7	9.4	3.0	12.4	3.2	7.2	7	9.0	3.3	27.7	3.2
	3rd	7.5	7	10.2	3.8	22.4	4.2	8.2	8	15.8	4.8	34.6	5.0
	Highest	6.7	7	21.0	4.7	115.3	5.4	7.4	7	17.9	4.9	108.3	4.5
	Test for trend	+		+		+		+**		+**		+**	

Lowest = Least aged / affluent quartile group, Highest = Most aged / affluent quartile group

Direction of trend (+ positive – negative) **: $P < 0.01$ *: $P < 0.05$ NS: No statistical significance

Table 4.3 reports the results of multiple logistic regression analyses conducted to examine the factors associated with park provision. After adjustment, it is evident that developers tend to open parks in more affluent and less aged communities. Population density and the number of parks already present also have a significant and positive association with the probability of developers opening new parks, whereas distance to the city centre has a negative association. These factors are likely a result of the fact that land provided by developers needs to be attractive to customers (Robinson and Robinson 1986). Meanwhile, land price has a significant and negative association. The model thus suggests that park provision by developers is at least partially driven by market mechanisms.

Table 4.3. Logistic regression model for new park provision between 1988 and 2005 by developers and city council

	Developers		City council	
	β	95% CI	β	95% CI
2nd quartile of pensioners (%)	0.024	0.770 , 1.363	- 0.237	0.600 , 1.038
3rd quartile of pensioners (%)	- 0.065	0.699 , 1.256	- 0.084	0.700 , 1.209
4th quartile of pensioners (%)	- 0.446**	0.456 , 0.898	- 0.064	0.696 , 1.265
2nd quartile of professional and managerial workers (%)	0.427*	1.086 , 2.162	0.331*	1.045 , 1.856
3rd quartile of professional and managerial workers (%)	0.484**	1.150 , 2.289	0.073	0.794 , 1.456
4th quartile of professional and managerial workers (%)	0.455*	1.096 , 2.267	0.026	0.749 , 1.408
Population density (100,00 people / km^2)	0.480**	1.208 , 2.162	0.334*	1.065 , 1.831
Number of parks pre-existing	0.047**	1.016 , 1.080	- 0.040*	0.929 , 0.994
Estimated land price (100,00yen)	- 0.005*	0.990 , 0.999	- 0.004	0.993 ,1.000
Distance to Yokohama centre (km)	- 0.050**	0.920 , 0.983	0.047**	1.016 , 1.080
Distance to Tokyo centre (km)	0.016	0.998 , 1.034	- 0.035**	0.950 , 0.981
N	6476		6476	
Cox & Snell R Square	0.023		0.022	

95%CI = 95% confidential interval
**: P < 0.01 *: P < 0.05
- 17 dummy variables measuring year (between 1989 and 2005) were incorporated into the model, but the results of them are omitted from the table for brevity. The base dummy is year 1988.

Table 4.3 shows no consistent association between the two demographic indicators and the odds of parks being provided by the city council, nor were land prices associated with provision. The number of parks already present had a negative association with the probability of the city of Yokohama opening a new park illustrating that the city council tends to provide parks in areas with fewer existing parks.

Table 4.4 shows the results of the model undertaken to investigate changes in population characteristics following park provision. Controlling for other characteristics, park provision by the city council was associated with increases in the percentage of professional and managerial workers for both 10 years and 15 years following park siting, suggesting the presence of move-in, although the effect sizes are small. No evidence was found that park provision was associated with a change in the percentage of pensioners. No associations were apparent for parks provided by developers possibly because, as previously noted, developers' parks are much smaller than those from the city council.

Table 4. Multiple regression analysis for changes in population characteristics after provision of parks

	Change in pensioners (%)						Change in professional and managerial workers (%)					
	(1988-2005)		(1993-2005)		(1998-2005)		(1988-2005)		(1993-2005)		(1998-2005)	
	β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	95% CI
(Constant)	0.46	-2.72, 3.65	-1.52	-4.22, 1.18	-3.27*	-5.78, -0.76	6.41**	4.08, 8.47	3.44**	1.72, 5.17	-0.06	-1.26, 1.14
Park Provision by developers	-0.17	-1.27, 0.93	-0.29	-1.26, 0.67	0.14	-0.79, 1.07	0.13	-0.73, 0.98	-0.14	-0.76, 0.49	-0.05	-0.50, 0.40
Park Provision by city council	-1.05	-2.12, 0.02	-0.39	-1.28, 0.51	0.46	-0.40, 1.31	1.31**	0.48, 2.13	0.70*	0.11, 1.29	-0.003	-0.42, 0.41
Population density (100,00 / km^2)	0.26	-1.00, 1.52	-0.56	-1.67, 0.55	0.09	-0.89, 1.07	-1.52**	-2.50, -0.54	-0.70	-1.43, 0.03	-0.12	-0.60, 0.35
Distance to Yokohama Centre (km)	0.06	-0.09, 0.21	0.17*	0.04, 0.29	0.26**	0.14, 0.37	-0.09	-0.21, 0.03	-0.06	-0.14, 0.02	-0.02	-0.08, 0.03
Distance to Tokyo centre (km)	0.28**	0.20, 0.36	0.21**	0.14, 0.28	0.10**	0.04, 0.17	-0.09**	-0.15, -0.02	-0.08**	-0.13, -0.04	-0.01	-0.04, 0.03
2nd Quartile of population characteristics (%) at baseline	0.28	-1.20, 1.61	1.64*	0.40, 2.88	0.56	-0.55, 1.67	-2.18**	-3.30, -1.07	-0.99*	-1.82, -0.16	-0.09	-0.63, 0.45
3rd Quartile of population characteristics (%) at baseline	0.50	-1.82, 0.98	1.71**	0.48, 2.93	1.16	-0.01, 2.32	-3.65**	-4.79, -2.50	-1.82**	-2.65, -1.00	-0.58*	-1.13, -0.03
4th Quartile of population characteristics (%) at baseline	1.26	-3.46, 0.41	-0.13	-1.45, 1.20	0.28	-0.92, 1.49	-6.69**	-7.87, -5.52	-3.35**	-4.24, -2.46	-0.70*	-1.25, -0.15
2nd Quartile of park area in previous year	0.20	-1.18, 1.74	-0.12	-1.41, 1.18	0.27	-0.85, 1.38	-0.98	-2.12, 0.16	-0.04	-0.90, 0.82	0.17	-0.38, 0.71
3rd Quartile of park area in previous year	-0.42	-1.01, 2.01	-0.06	-1.32, 1.20	0.62	-0.50, 1.73	-0.61	-1.79, 0.57	-0.06	-0.91, 0.80	0.12	-0.42, 0.66
4th Quartile of park area in previous year	-1.93*	-0.16, 2.69	1.27*	0.05, 2.50	0.60	-0.49, 1.69	-0.02	-1.16, 1.12	-0.10	-0.95, 0.74	0.37	-0.17, 0.90
N	353		355		361		353		355		361	
R Square	0.158		0.187		0.086		0.388		0.234		0.006	

95% CI = 95% confidential interval **: P < 0.01 *: P < 0.05

Table 4.5 reports the results of the hedonic pricing models of land and property prices. Both models illustrate that, when all other variables are controlled, accessibility to parks has positive and significant association with land and property prices. This provides some evidence that park provision may cause land and property prices to rise.

Table 4.5. Result of hedonic pricing models for natural log of land price and natural log of detached house price

	Land price model		Property price model	
	β	95% CI	β	95% CI
(Constant)	3.395**	3.361, 3.429	3.395**	3.383, 3.407
Ground area (m^2)	0.001**	0.001, 0.002	Excluded	
Floor space (m^2)	Excluded		0.003**	0.003, 0.003
Width of front road (m)	0.012**	0.011, 0.013	0.003**	0.002, 0.003
Private road dummy	- 0.028**	- 0.038, - 0.018	- 0.022**	- 0.025, - 0.019
Residential zoning dummy	0.016*	0.002, 0.030	0.027**	0.022, 0.031
South-facing dummy	0.019**	0.008, 0.031	NS	
Reinforced concrete dummy	Excluded		- 0.032**	- 0.044, - 0.021
Population density (100,00 people / km^2)	0.012*	0.003, 0.021	NS	
Professional and managerial workers (%)	0.008**	0.007, 0.009	0.006**	0.006, 0.006
Distance to Yokohama centre (km)	NS		0.003**	0.003, 0.004
Distance to Tokyo centre (km)	- 0.006**	- 0.007, - 0.006	- 0.003**	- 0.003, - 0.003
Distance to elementary school (km)	NS		- 0.008**	- 0.014, - 0.002
Travel time to closest rail station (min)	- 0.004**	- 0.005, - 0.004	- 0.002**	- 0.003, - 0.002
Cross term between bus using dummy and travel time to closest rail station	- 0.001**	- 0.002, - 0.001	- 0.001**	- 0.001, - 0.001
2nd quartile of park area	0.022**	0.013, 0.031	0.005**	0.001, 0.008
3rd quartile of park area	0.035**	0.026, 0.045	0.017**	0.014, 0.020
4th quartile of park area	0.049**	0.040, 0.058	0.027**	0.024, 0.030
Year 2000 dummy	- 0.073**	- 0.081, - 0.064	- 0.088**	- 0.091, - 0.085
Year 2005 dummy	- 0.140**	- 0.149, - 0.131	- 0.153**	- 0.156, - 0.150
Market reservation time (month)	NS		0.002**	0.002, 0.002
N	5828		26486	
R Square	0.618		0.591	

95% CI = 95% confidential interval
**: P < 0.01 *: P < 0.05 NS: No statistical significance
Excluded: excluded variables to avoid multi-collinearity

4. Discussion and conclusion

By conducting a case study of Yokohama, we used longitudinal modelling to identify the processes potentially responsible for generating environmental equity in park accessibility. First, we found that a strong association existed between inequity in park accessibility and affluence over the past 18 years in the city. We also observed that in more affluent communities and those with lower percentages of pensioners, developers tended to build more parks, although they are likely to be smaller than those built by the city authority. Nevertheless, the long term, the cumulative effect of the disproportionate siting of parks built by developers over several decades may increase the disparity. Interestingly, the development of parks by the city council was found to be associated with a subsequent rise in the affluent population in the area, although the effect sizes were small. No such effect was observed in the case of parks built by developers. Whilst our hedonic pricing model indicated that park provisions may increase land and property prices, which may amplify the existing inequity in park accessibility, placement of parks is thus observed to have little effect on subsequent change in population characteristics.

Our original concern was that unequal political power between different social groups may cause disproportionate park provision between communities (Boone et al. 2009, Talen 1998); however, it was evident that the city authority provides parks according to pre-existing levels of park provision rather than population characteristics across areas. Further, although we found that developers tend to build parks in socially advantaged areas, their behaviour seems to be market driven rather than a result of the political influence of the local people. We also found that developers are likely to choose areas with a cheaper land price to build parks, a likely consequence of the nature of their business.

We suggest several policy implications to remedy environmental inequity in park accessibility. Perhaps the most important and effective remediation measure is the direct placement of parks by the city council in socially disadvantaged areas with limited parks. As we observed that park provision has little effect on the reallocation of population characteristics, we suspect this would not have act to drive out those disadvantaged residents in the long-term. The provision of bond funds and other legislation to encourage park siting by private developers in disadvantaged areas may also have a role to play (Wolch et al. 2005).

Our study has a number of strengths and weaknesses. Some authors have mentioned that the limited number of longitudinal studies in the equity field is a result of the limited availability of historical data (Mohai 2008, Saha and Mohai 2005, Liu 2001); historical data on both population and environmental quality is sometimes not digitised or inconsistent with contemporary information. In countries such as the USA, census tract boundaries change and this can cause problems. A strength of our work is thus the use of grid-based census data that circumvented the problems of boundary change. Furthermore the production of maps of park provision meant we were able to examine changes in park provision over a long period of time.

Whilst we examined a wide range of explanatory variables we were not able to measure all characteristics of the environment that may result in the changes in population characteristics and in land and property prices we observed. For example other environmental improvements may have taken place that we did not measure, and the introduction of environmental disamenities such as hazardous waste sites, may have occurred. Because we have conducted a number of statistical tests, some of the significant associations we observed may be due to chance. The fact that Japanese census data was only available for 5 year periods meant that we were not able to look at changes in population at a finer temporal resolution and our analysis would not detect changes that occurred very shortly after parks were provided. Nevertheless, the availability of data every 5 years improves on many countries where only a decennial census is available. Since our interest was to look the effect of affluence on park provision, we focused on the percentage of professional and managerial workers as a target population group. However, it can be alternatively postulated that an impoverished population may move out after park siting, since park provision drives up the property price in the neighbourhood, something that we were unable to test. Finally, there are several limitations related to our measurement of park accessibility. We did not have information of the location of park entrances and, although Al-Taiar et al. (2010) noted that Euclidean and road network distances are highly correlated, our use of Euclidean rather than road distances is a simplification. Moreover, we focussed solely on park provision, whilst other attributes of parks, such as the facilities they provide, may also affect their value to society.

To our knowledge, this study is one of the first attempts to test the potential causal hypotheses of amenity accessibility from an amenity perspective. Further work is required to confirm out findings in other settings. We hope this may assist in the development of remediation policy, as well as improving our understanding of the underlying process that generate inequity.

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Chapter 5
Virtual city models for assessing environmental equity of access to sunlight: a case study of Kyoto, Japan

Abstract
Virtual city modelling is expected to play a central future role in the field of urban planning and design. Currently, most of the uses of this modelling method are related to the production of visualizations, but there is also a potential for developing novel methods of spatial analysis that focuses on vertical variations in, for example, building heights. One application concerns the assessment of access to sunlight. This is an essential consideration in urban planning, and there is considerable demand for geographical information systems which can provide efficient solar radiation analyses. Nevertheless, few studies have attempted to model variations in sunlight exposure over entire urban areas. This article illustrates an application of solar radiation analysis using a detailed virtual urban modelling for the city of Kyoto, Japan, as a case study. The research presents and implements a methodology to examine how sunlight access varies between different social groups in the city. The findings, which show evidence of inequity, illustrate the potential of virtual city models and these benefits are discussed along with the caveats of their application.

1. Introduction

In the 1990s, increased demand for digital information on the structure and design of cities, coupled with a greater availability of computing power, encouraged the development of novel digital urban modelling and representation techniques (Evans et al. 2005 and Hudson-Smith 2008). In particular, advances in geographical information systems (GIS) technologies and the improved availability of digital data allowed a new generation of three dimensional (3D) virtual city models to be produced (ibid). Dodge et al. (1997) described a virtual city model as a three dimensional urban representation employing 3D-GIS/virtual reality techniques to depict realistic buildings and provide a wide range of services, functions, and information. The use of these virtual models is expected to play a central role in the field of urban planning and design in coming decades.

In recent years much research and discussion have been undertaken to examine the uses of virtual city models in the field of urban planning. Most of the potential applications benefit from two key advantages of virtual city models; the potential to undertake 3D visualization and 3D spatial analyses that focus on vertical variations in building heights (Kurakula and Kuffer 2008). For example, Yano et al. (2007) demonstrated several uses of virtual city modelling (Virtual Kyoto model) for landscape management, including visualizing current and past city landscapes simulating future landscapes, and generating visibility maps employing viewshed analysis. Kolbe et al. (2005) also discussed several potential uses of virtual city modelling for hazard management, such as determining escape routes inside and outside of buildings, and examining effects of floods on building storeys under a range of scenarios.

In this chapter, we examine how the application of virtual city models might contribute to the estimation of solar radiation in an urban context, using a case study of environmental equity of access to sunlight. Conserving access to sunlight is regarded as an essential part of city planning since sunshine is closely related to living standards (Kobayashi 1974). Laws relating to the conservation of access to sunlight exist in many countries. For instance, the Zoning Law of 1916 in New York was enacted to set height and set-back restrictions for buildings in order to preserve sunlight exposure (Weiss 1992). The California solar rights act of 1978 was enacted to protect installations of solar energy technology by restricting obstructions of access to sunlight caused by neighbouring buildings (Anders et al. 2010) Furthermore, there are various regulations which specify minimum recommended levels of sunshine duration for residential buildings in Asian, European and Northern American countries (Qian 1995). The availability of sunlight is also enshrined in culture, and thus there is a substantial demand for efficient and accurate calculation of solar radiation, with several methods being used (for example see Morello and Ratti 2009). Good access to sunlight is important for two principal reasons. Firstly, there are known positive influences on general quality of life (Kobayashi 1974 and Yoshimi 1999) as the effects of heating, drying and lighting provided by sunlight have all been shown to be important determinants of well-being. Secondly, exposure to sunlight has positive effects on health (ibid). For example, exposure to sunlight has been shown to be positively related to recovery from symptoms of depression (Beauchemin and Hays 1996 and Bendetti et al. 2001) and negatively related to the degree of one’s sense of being healthy (Sakabe and Yamazaki 1999).

As a consequence of positive benefits of sunlight, and given that the effects of shading mean that competition for the resource exists in the urban environment, it is useful to consider whether access to sunlight is equitably distributed in the population. Early environmental equity analyses focused primarily on environmental disamenities, such as the proximity to waste management plants or exposure to air pollution (e.g. Zimmerman 1993 and Perlin et al. 1995). However, in recent years, access to positive amenities such as green spaces or hospitals has also a focus (e.g. Jones et al. 2009 and Christie and Fone 2003). Jones et al. (2009) defined equity in access to such amenities as an equal opportunity standard among different socio-economic groups. In the work we present here, we thus define equity of access to sunlight as the equal distribution of possible sunshine duration on buildings regardless of the socio-demographic characteristics of their residents.

Prior to the availability of virtual city models, several methods were used to assess the possible sunshine duration in buildings, including site visits, handwritten shadow diagrams and physical models that use light rays (Matsuura and Takahashi 2001). More recently CAD based software packages have been developed, but they are generally only capable of considering a single structure of limited number of buildings in a small area, a limitation which reflects the fact that they have been designed for architects to calculate how a newly-constructed or proposed building may interfere with another buildings' access to sunlight. In this work we make use of the 'Virtual Kyoto' model produced for the city of Kyoto, Japan. Japan is particularly appropriate for this case-study because, during the 1960s and 70s, high-rise buildings were constructed rapidly in Japanese cities with few controls or regulations, interfering with the access to sunlight of neighbouring residences. As a consequence newly introduced regulations set several construction standards on buildings, including height limitations. Civil law also states that, if a newly constructed building interferes with a neighbours' access to sunlight and violates the standard maximum permissible level, the victim can sue for compensation or an injunction (Yoshimi 1999).

In this article, we firstly present a methodology to estimate possible sunshine duration upon buildings in an urban context using the Kyoto virtual city model, before applying it to examine environmental equity of access to sunlight in Kyoto.

2. Data and methodology

2.1. *Study area*

The case study city of Kyoto (Figure 5.1) is the seventh most populous in Japan, located at a latitude of 35 degrees north and with a population close to 1.5 million. Formerly the imperial capital of Japan, it is now the capital of Kyoto Prefecture, as well as a major part of the Osaka-Kobe-Kyoto metropolitan area. Kyoto is located in a valley, part of the Yamashiro (or Kyoto) Basin. With over 2000 religious places, as well as palaces, gardens and early architecture intact, it is one of the best preserved cities in Japan.

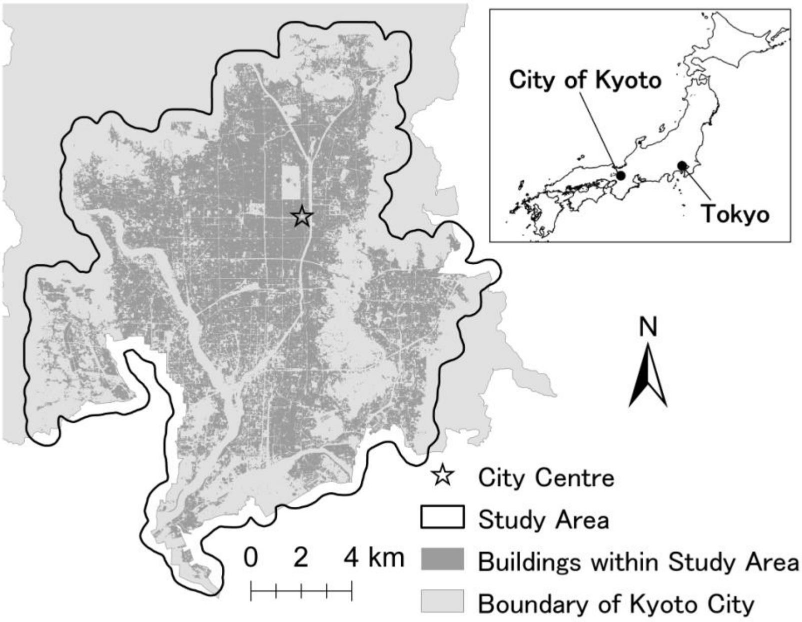

Figure 5.1. The study area in the city of Kyoto

2.2. ***Data - the 'Virtual Kyoto' model***

Table 5.1 lists details the datasets used in the analysis. The principal data source, the 'Virtual Kyoto' model, was developed by the GIS research team at the Ritsumeikan University in Kyoto. The production of the model is described in detail in Yano et al. (2007) and is hence only briefly recounted here. Two different commercially available building shape polygons, MAPCUBE and Z-Map Town II, were predominantly used to generate the building model. The former is composed of prismatic three dimensional structure models which use building footprint data and air-borne laser profiler data to measure height values at an interval of 2.5m (Yano et al. 2008) (Figure 5.2). Z-Map Town II contains varied items of information including the use of each structure, for example commercial or residential. In order to generate these attributes, the company ZENRIN undertook house-to-house surveys within Kyoto city.

Table 5.1. Details of datasets used in the environmental equity analysis

Name	Type	Contents	Publisher	Year
MAPCUBE (Building shape)	Polygon	Building shape and height (scale: 1/2500)	Increment P, co CAD centre, co	2002
MAPCUBE (Elevation)	Point	Elevation of land (horizontal resolusion:2.5m) (vertical accuracy:±15cm)	PASCO, co	
Z-Map Town II (Building shape)	Polygon	Use of each building (scale: 1/2500)	Zenrin co., ltd.	2000
Digital Map 50m Grid (Elevation)	Point	Elevation of land (horizontal resolusion:50m) (vertical accuracy:±7.5m)	Geographical Survey Institute	1986
Census record (Tabulation for small areas)	Attribute	Population characteristics at each small census area	Japan Ministry of Internal Affairs and Communications	2000

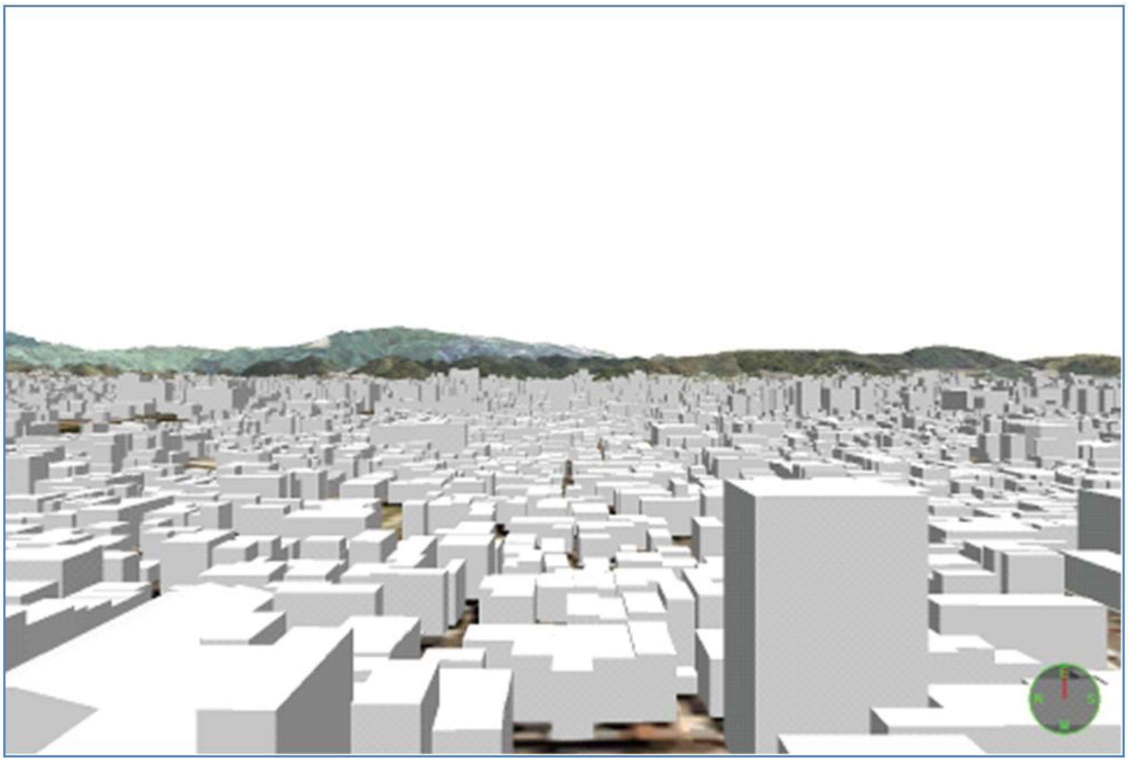

Figure 5.2. Building shape polygons from MAPCUBE

The polygons from MAPCUBE had detailed and accurate building shapes, whereas those from Z-Map Town II have crude building boundaries since the boundaries equate to lots rather than the buildings themselves. Building centroids from Z-Map Town II were thus overlaid on the polygons of MAPCUBE to generate the accurate building shape data, as depicted in Figure 5.3. The output contained information on both the height and the use of each structure (see Yano

2006).

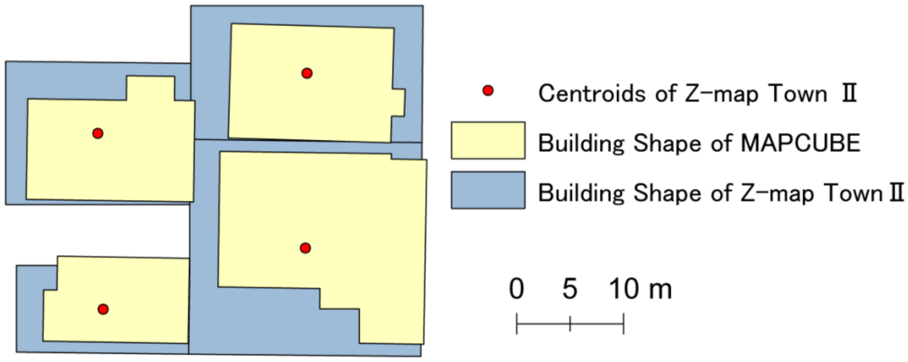

Figure5. 3. The method used to combine the two building datasets

2.3 Analytical methods

All the GIS analyses were undertaken in ArcGIS 9.3 (ESRI Inc) and all statistical analyses were done using SPSS 16.0 (SPSS Inc). For the calculation of possible sunshine duration, two types of data were required in addition to the Virtual Kyoto model; a Digital Surface Model (DSM) and positional data on calculation points for sunshine duration (ESRI 2008).

To generate the DSM used in this analysis, we firstly created a Digital Elevation Model (DEM) using the 'MAPCUBE (elevation)' and 'Digital Map 50m Grid (elevation)' datasets. Both types of data are point based, recording the elevation of the land surface at equally spaced intervals. The former covers the urbanised parts of the city, whilst the latter covers the surrounding mountain areas. These two sets of points were merged and converted into a raster layer at a 1m horizontal resolution. Next, the building data outlined above was converted into a 1m raster grid, with each raster cell recording the height of the building it fell within. These values were then added to the DEM to generate a 1m resolution DSM of Kyoto city.

Since the focus of this research was on the relationship between population characteristics and access to sunlight, only residential buildings were chosen to determine the positions of calculation points for possible sunshine duration. Firstly, each building polygon was split into sidelines, and south, east, west and north-facing walls were selected. The midpoint of each wall was then identified and was used to determine the calculation points (Figure 5.4). Because of the 1m raster resolution used, there was a possibility that some points would fall inside a building boundary. To avoid this, each was moved 1m away from the building polygon boundary.

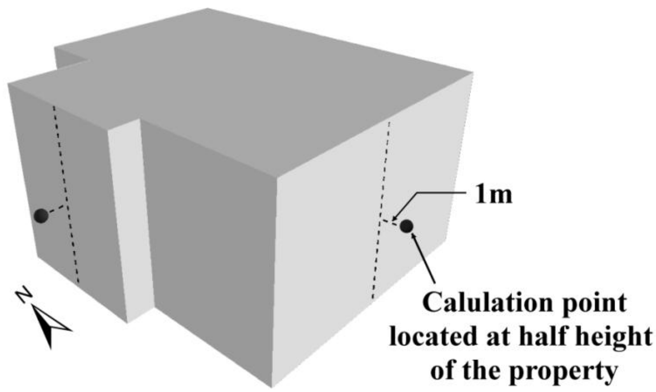

Figure 5.4. The location of calculation points on buildings

The heights at which possible sunshine duration was measured were computed in one of three ways. For building boundaries that were not contiguous with a neighbouring property, the height was set to be half of the height of the property. In cases where the boundary was shared with a neighbouring structure which was lower than half its height, the offset was set to be the difference between the neighbouring building height and the midpoint of the building. Where a neighbouring contiguous property was higher it was assumed that a calculation point had no exposure to direct solar radiation.

For each property, three sunlight related metrics were computed; a binary measurement of whether or not any direct solar radiation was exposed on any of calculation points in each property, the average value of possible sunshine duration across all calculation points of each property, and the value of sunlight duration at the point which received the longest possible sunshine duration. This maximum value was considered in addition to the average as the main living area of the property will have often windows along this boundary, and hence this metric captures the most typical sunlight exposure for occupants. All these metrics were computed for a single date; that of the winter solstice (December 21st). This was chosen as it is the day for which the effects of any shading present would be expected to be greatest in the northern hemisphere.

The calculation of possible sunshine duration was undertaken using the ArcGIS Points Solar Radiation Tool. Firstly, an upward-looking hemispherical viewshed (view of the whole sky from the ground up) for each calculation point was generated in the DSM (ESRI 2007). This is a raster-based representation of the whole sky, where each pixel identifies whether each corresponding sky location is visible or not when viewed from the calculation point. Next a sun map was generated for each point. This is a raster-based representation of the sun track at the latitude of the calculation point. The viewshed was then overlaid on the sun map to identify which parts of the sun track were obstructed. By counting the unobstructed length of the sun map, the possible sunshine duration for the calculation point was calculated (see Figure 5.5). Other input parameters were set to be the same values as those shown to be optimal by Fu and Rich (1999); the number of directions on the viewshed was 64; the resolution for viewshed and sun map was 512 × 512 pixels; and the temporal resolution of the sun map was 0.1 h.

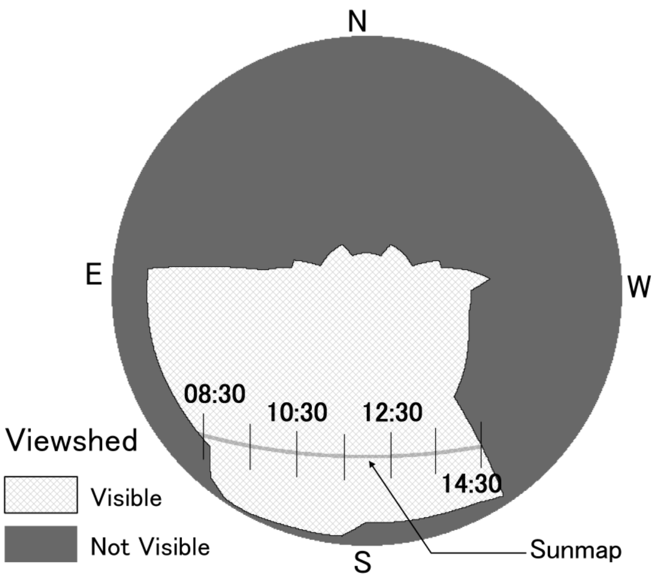

Figure 5.5. The calculation of sunshine duration on a sample calculation point on the winter solstice 2000

The generation of the sunlight metrics for each calculation point was found to be particularly computationally intensive. When the input DSM covered the whole of the study area, the computing power provided by a multi-core PC proved insufficient for the routines to run to completion in ArcGIS. Consequently, the DSM was split into small parts centred on each calculation point. Test simulations suggested that approximately 30 seconds were required to extract the DSM and calculate the possible sunshine duration for each calculation point. As there were over 330,000 residential properties in the study area, the process would have taken over 110 days to complete. These computational considerations meant stratified random sampling was used to compute the sunlight metrics for a sub-sample. The strata were selected using two measures, one capturing affluence and the other the physical structure of properties. From the 2000 Japanese Census, the percentage of professional/technical workers and managers and the percentage of detached houses in small census areas were obtained. All properties were assigned to one of 25 groups based on the combined quintiles of each of the two variables within which they fell. An equally sized random sample of properties was then selected from within each quintile to provide a sample of 5400 properties, around 2% of the total number present.

The socio-demographic characteristics of the population of Kyoto used in the equity analysis were also extracted from the 2000 Japanese Census at the small census area level. Age group is a frequently used indicator in equity analyses (e.g. Brainard 2002, Mitchell and Dorling 2003) because it is an important determinant of each person's vulnerability and life patterns (Liu 2001). In particular, an older population may be more susceptible to environmental disamenities due to poorer health status and decreased mobility and social activity (Sexton et al. 1993). For the purpose of our age group analysis we thus focused on pensioners (over 65 years old). The Japanese Census does not record incomes but does hold information on occupation and educational level, both of which can proxy the affluence level of each small census area. For this analysis we computed the percentage of professional and technical workers and managers (high affluence) in each census area, and the percentage of residents with either a degree or postgraduate qualification (graduates).

The relationship between the measures of access to sunlight and each of the social indicators was investigated by classifying census areas into quartiles based on each indicator and examining how the three sunlight measures varied across the quartiles. We also undertook a sensitivity analysis using a sample of 1000 randomly selected calculation points to examine how possible sunshine duration was influenced by both the distance around each building within which other buildings were considered, and the horizontal resolution for the DSM. For the former we repeated our calculations using a 1m DSM resolution for different distances of 50m, 100m and 500m. For the latter, three DSM cell sizes (0.5m, 1m and 2m) were examined using a maximum distance of 100m.

3. Results

Figure 5.6 maps the spatial distribution of average sunshine duration (a) and quartiles of the socio-demographic indicators within the city. The unshaded areas in the figure are those that fell outside the sampling framework for this analysis, and hence no measures of sunlight duration were available for them.

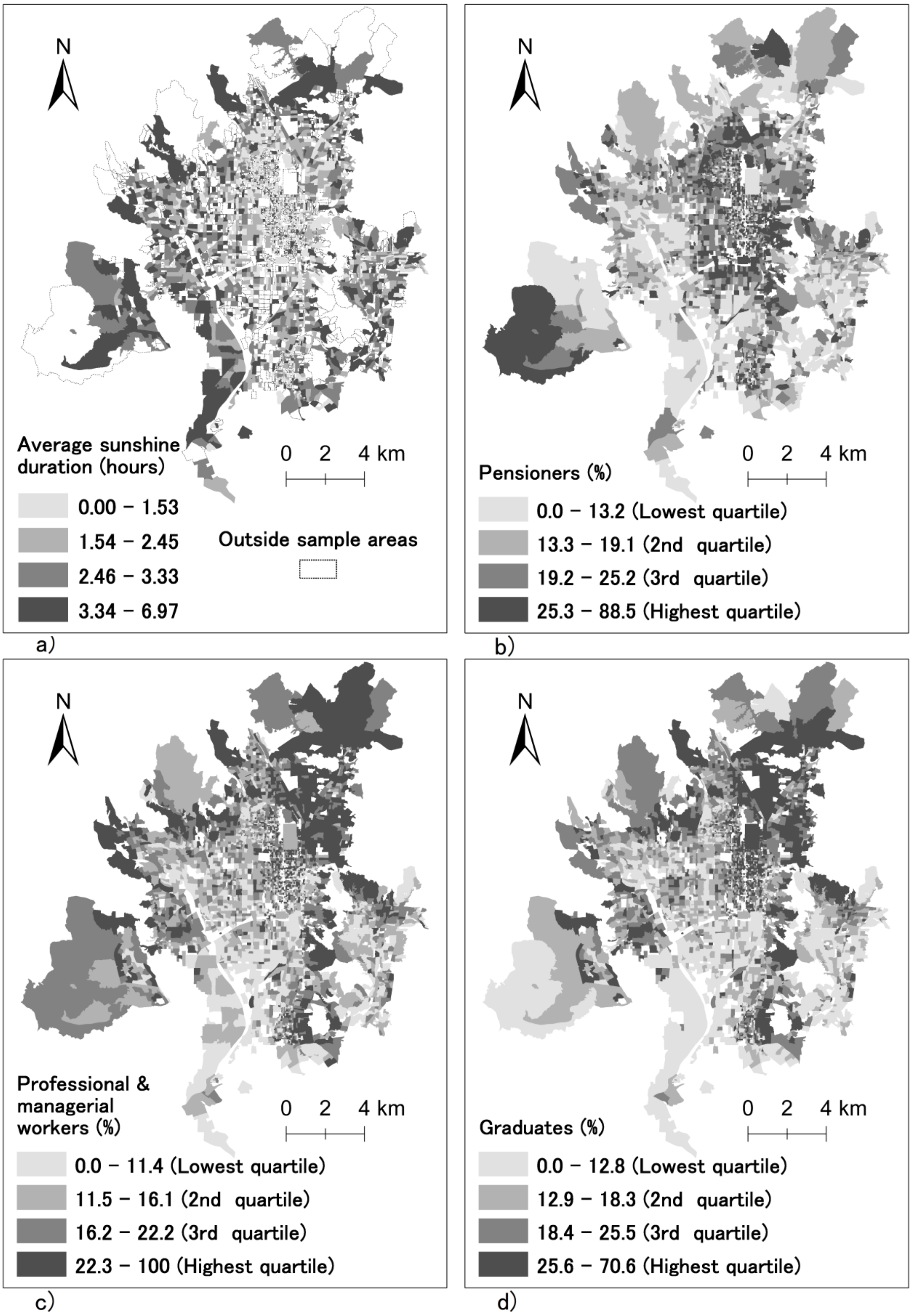

Figure 5.6. The spatial distribution of access to sunlight and social indicators: (a) Average sunshine duration (hours); (b) Pensioners (%); (c) Professional & managerial workers (%); and (d) Graduates (%)

The first rows in Table 5.2 show the odds of receiving any direct solar radiation at a particular point on the building on the winter solstice according to quartiles of each social indicator. In total, 4.2% of the entire sample was modelled as having no access to sunlight on the winter solstice in Kyoto. The trends in odds across quartiles of retired populations suggest that properties in communities with older residents are considerably less likely to receive any direct solar radiation. There is also a statistically significant increase in the odds of properties having access to sunlight with an increasing percentage of the population working professional or managerial jobs. A weaker trend, not statistically significant, is also apparent with the percentage of the population educated to degree standard or above.

Table 5.2 also shows the mean values of possible average and maximum sunshine duration across quartiles of the social indicators. For retired populations there is again clear evidence of inequities; both average and maximum values of possible sunshine duration show statistically significant declines with an increasing percentage of pensioners. Both average and maximum values are also related to affluence levels measured according to employment type, with lower values in census areas with fewer residents employed in professional and managerial occupations. No trend was apparent for education.

Table 5.2. Results of equity analyses: Odds ratios of receiving sunlight, distribution of average sunshine duration (hours) and distribution of maximum sunshine duration (hours). Direction of trend (+ positive – negative) is also reported.

	Pensioners (%)		Professional & managerial workers (%)		Graduates (%)	
Odds ratio of Receiving sunlight	OR	95% CI	OR	95% CI	OR	95% CI
Lowest Quartile	1		0.53	0.36 - 0.80	0.78	0.52 - 1.16
2nd Quartile	0.79	0.50 - 1.24	0.62	0.41 - 0.93	0.67	0.46 - 0.99
3rd Quartile	0.58	0.37 - 0.88	0.68	0.45 - 1.03	0.80	0.53 - 1.19
Highest Quartile	0.36	0.24 - 0.54	1		1	
Test for trend	– **		+ **		+ NS	
Distribution of average possible sunshine duration (hours)	Mean	95% CI	Mean	95% CI	Mean	95% CI
Lowest Quartile	2.81	2.73 - 2.88	2.34	2.26 - 2.42	2.46	2.38 - 2.53
2nd Quartile	2.54	2.46 - 2.62	2.46	2.38 - 2.54	2.39	2.31 - 2.47
3rd Quartile	2.38	2.30 - 2.45	2.50	2.42 - 2.58	2.47	2.39 - 2.54
Highest Quartile	2.03	1.95 - 2.10	2.45	2.37 - 2.53	2.44	2.36 - 2.52
Test for trend	– **		+ *		+ NS	
Distribution of maximum possible sunshine duration (hours)	Mean	95% CI	Mean	95% CI	Mean	95% CI
Lowest Quartile	5.98	5.85 - 6.11	5.22	5.08 - 5.36	5.41	5.28 - 5.54
2nd Quartile	5.61	5.48 - 5.74	5.40	5.26 - 5.53	5.27	5.14 - 5.41
3rd Quartile	5.29	5.15 - 5.42	5.50	5.37 - 5.63	5.46	5.33 - 5.60
Highest Quartile	4.68	4.55 - 4.82	5.45	5.32 - 5.59	5.42	5.28 - 5.56
Test for trend	– **		+ **		+ NS	

Lowest Quartile = Least aged / affluent quartile group
Highest Quartile= Most aged / affluent quartile group
OR = Odds ratio   95% CI = 95% confidential interval

**: P < 0.01 *: P < 0.05 NS: No statistical significance

Table 5.3 shows the results of the sensitivity analysis. The outcomes for the computation of possible sunshine duration for the 100m and 500m buffers were completely identical to two decimal places, with that for the 50m buffer being very similar. This suggests, in Kyoto at least, a 50m radius is sufficient. The effects of all three DSM resolutions are also almost identical. This suggests that smaller cell sizes increase computational overheads but does not affect results, and thus a 2m resolution is sufficiently small for this purpose. Because the sensitivity analysis did not reveal large differences in computed values, the equity analysis was not repeated for each of the sensitivity parameters tested.

Table 5.3. Estimated sunshine duration (hours) at each calculation point in the sensitivity analysis

	Maximum Distance			DSM horizontal Resolution		
Duration	50m	100m	500m	0.5m	1m	2m
Mean	3.29	3.23	3.23	3.25	3.23	3.21
25%ile	0	0	0	0	0	0
50%ile	2.87	2.79	2.79	2.80	2.79	2.74
75%ile	5.52	5.44	5.44	5.48	5.44	5.43
Minimum	0	0	0	0	0	0
Maximum	9.63	9.63	9.63	9.63	9.63	9.63

4. Discussion and conclusion

This research was undertaken to illustrate how a virtual city model may be applied in the field of environmental equity analysis. Using the case study of Kyoto city, the distribution of access to sunlight among different social groups was estimated, revealing evidence of inequity in access to sunlight, particularly by population age. Therefore we have illustrated one way by which virtual city models can be used to model complex environmental phenomena that require a consideration of three dimensions.

Although this work has illustrated the potential of the technologies, it has also revealed a number of limitations. In particular, the accuracy of the methodology will be dependent upon the quality of the data available. Whilst the Virtual Kyoto model we employed provided accurate building representations, it did not include information on vegetation. Particularly for lower buildings, shading from trees might be significant, although it may be the benefits of living in an environment with such greenery will compensate for any loss of sunlight (Gao and Asami 2001, Gao and Asami 2007). The issue of non-representation of certain features has been discussed by Fu and Rich 1999. An additional limitation was that we did not have information on the location of windows in the buildings, and hence we used assumed points for our calculations. The output of our analysis is based on direct radiation only, whilst collected solar energy and diffuse plus reflected radiation can make a significant contribution in latitudes such as those where Kyoto is situated. Furthermore, our estimates of sunlight exposure were based on cumulative radiation received throughout the day, whilst the effects of sunlight during the middle of the day can differ from that during the early morning or late afternoon due to the angle of the sun and different luminance levels (Morello and Ratti 2009). Kyoto is a city which is surrounded by mountains, but considerations relating to computational overheads meant that we were not able to include them in our analysis. Nevertheless, it is likely that the effect of the mountains on our measures of cumulative sunlight exposure throughout the day would be minimal.

A further limitation of this work was that we were only able to consider sunlight exposure on the outside walls of each property rather than that entering the rooms. This will be affected by the characteristics of the windows, including their location, material, and proximity to eaves (Tanaka et al. 2006). In the absence of such information we assumed the calculation points are representative of the actual location of the windows, although windows locations could be used in our methodology if information was available. Another point to note is that the height limitation policy in Kyoto is relatively strict compared to other cities, due to the city's long history and popularity as a tourist attraction (see Kyoto City Council 2007). Hence the residences in Kyoto are more likely to have superior access to sunlight than those in other cities. Despite this, our research found that there were still inequities in access to sunlight in Kyoto. In other urban areas any disparities may be more considerable, although this is as yet untested.

We recommend several possible future directions for GIS based solar radiation analyses. One aspect not considered here is the energy-saving potential of solar radiation. Heating buildings using solar gain can make some contribution towards greenhouse gas emissions reduction strategies and we therefore suggest that future work may consider this potential (for example, see Morello and Ratti 2009). Furthermore, GIS based methodologies have recently been developed that illustrate the potential of mapping technologies to assess the viability of photovoltaic installations (see Wiginton et al. 2010) and clearly the work we present could be an important input into this process. Secondly, in this work we undertook some relatively simple sensitivity analysis to test for the effect of search distance and cell resolution and, whilst we found our findings to be relatively insensitive to parameterisation within the range we tested, further work using probabilistic distributions should be undertaken to examine the effects of error and uncertainty in the DSM used (e.g. Wu et al. 2008). Other software packages (e.g. Geographic Resources Analysis Support Systems (GRASS) (Neteler and Mitasova 2008)/ CADs (e.g. A&A Shadow produced by A&A Co., Ltd.) are available to estimate solar radiation (for example see Gao and Asami 2001), yet they all use different computational algorithms. The effect of algorithm choice on results obtained is not known and further work should be undertaken to test this.

Our findings suggest that increased efforts for enforce those policies that do exist may be required. Pastor et al. (2001) suggest two drivers that act to generate environmental inequity: an unequal distribution of political power and the effect of unregulated market mechanisms. Based on this it is possible to suggest policy responses to the observed inequities. Environmental disamenities such as unwanted shading might be disproportionately sited in disadvantaged communities due to the presence of political inequities between different social groups, especially where disadvantaged communities have limited political power to resist them. Whilst Japanese civil law guarantees the right to access to a satisfactory level of sunshine, it is known that deprived population groups often have a limited ability to overcome the construction of new buildings in their neighbourhood since they rarely possess the resources to challenge any actions leading to the inequities (Miyake 1971). Re-examining zoning and height limitation legislation so it explicitly promotes equal access to sunlight may hence be one policy response (Pastor et al. 2001). Market dynamics could also result in the observed inequities as the land prices in environmentally disadvantaged areas are often relatively low leading to the in-migration of more vulnerable population groups. Several policies to help remedy problem have been suggested, including income redistribution programmes, initiatives to help socially disadvantaged individuals to secure equal opportunities to rent or purchase housing, and the careful placement of low income housing (Been 1994).

Although our focus was on the duration of sunshine inside properties, the provision of opportunities to enjoy sunshine outdoors may act as a partial solution to observed inequities. Miyake (1971) suggested that constructing new parks in communities that suffer from disproportionate amounts of shading may be beneficial, especially as the important role of parks in recreational walking is well known (Giles-Corti et al. 2005). Such benefits may be particularly important for the elderly, and we suggest that the process of planning for park provision might better take account of the distribution of access to sunlight among the populations that the parks are designed to serve.

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Chapter 6
The use of a virtual city model for assessing equity in access to views

Abstract

The development of virtual city models has provided novel possibilities for analyses that require consideration of building heights in urban areas. The study was undertaken to explore these possibilities by using the virtual Kyoto model to examine equity in access to views in the Japanese city. A sample of just over 5000 residences was selected by stratifying for population age and affluence. A series of viewsheds were computed to quantify the visibility of a range of environmental amenities (greenspaces, water bodies, historical buildings, mountains) and disamenities (factories and roads). Evidence of inequity in visual amenity was identified, whereby homes in areas with many old people were much less likely to have views of greenspaces and water bodies, although they were also less likely to see factories and roads and were more likely to view mountains. Homes in more affluent areas had better views of greenspaces, historical buildings, and mountains, and were less likely to see factories and water bodies. We discuss the potential of virtual city models for furthering analyses of the urban environment and raise some caveats regarding their use.

1. Introduction

The widespread adoption of Geographic Information Systems (GIS) in the past two decades has had a significant impact on research related to the fields of urban planning and design (e.g. Murayama and Shibazaki 2008, Bateman et al. 2002, Higgs 2004). One of the most significant advances is the development of virtual city models, which show particular promise for new directions in urban planning (Evans et al. 2005, Shiode 2001, Nakaya et al. 2010).

A virtual city model is a three-dimensional urban representation which is produced and stored in a GIS or similar Computer Aided Design (CAD) package. Virtual city models often use virtual reality techniques to depict realistic buildings and supply various services, functions, and information contexts (Dodge et al. 1997). A particular advantage of the use of these models is that they provide information on vertical variations in building heights (Kurakula and Kuffer, 2008), and many of their current applications are based on this attribute. For example, Kolbe et al. (2005) introduced several potential uses of the models for hazard management, including examining effects of floods on building storeys under a range of scenarios. Kurakula and Kuffer (2008) also demonstrate noise modelling in an urban model which allows estimates of noise exposure at the population level to be computed considering the elevation of buildings and the presence of noise barriers. Using a case study of a university campus, Thill et al. (2011) demonstrated the feasibility of using three dimensional urban models for novel forms of route planning which consider vertical movements of individuals within buildings as well as between them, as well as the optimal placement of facilities within the buildings.

One area within which, to our knowledge, virtual city models have not yet been applied is in the assessment of equity of access to scenic amenity, which we define as views of landscape elements which are positively valued by society, or attractive views, amongst urban residents. We believe they possess considerable potential for this type of work. Attractive views are valued as they have been repeatedly shown to provide high levels of visual amenity, as well as more generally enhancing quality of life and the living environment (Thompson et al. 2010 and Tyrväinen and Miettinen 2000). Being able to view nature from windows has been shown to be a determinant of good general health and well-being (Hartig et al. 2003, Kaplan 1993, Kaplan 2001, Ulrich 1984). Cavailhès et al. (2009) have also shown that having direct views of different land types is more influential on property prices than those types that actually surround a property but cannot be seen.

There are several methods that have previously been employed to quantify the characteristics of the views that people experience of their surrounding landscapes. Most simply, metrics may be calculated based on the distance between an observer and some object or objects of interest (e.g. Garrod and Willis 1992a). Under such analyses, close objects are assumed to be more visible whilst those more distant are classed as less so. However the technique lacks precision since unconsidered landscape elements, such as buildings or other topological features, might stand between the observer and a feature being considered. Alternatively, site visits can be made in order to take photographs or videos which can subsequently be used to rate the quality of views (e.g. Anderson and Cordell 1988, Luttik 2000). These methods facilitate the capture of detailed landscape elements such as roadside trees, but collecting a sufficient number of samples for analyses can be labour intensive (Paterson and Boyle 2002, Yu et al. 2007). It has also been noted that these methods may not provide a consistent categorisation of views across observers due to their subjective interpretation (Paterson and Boyle 2002, Yu et al. 2007).

Most recently, viewshed analysis techniques have been developed using GIS. A viewshed is a spatial layer which identifies inter-visibility between specific locations in a landscape, and can encompass digital land surface models, data on the heights of buildings and other notable obstacles, as well as maps of land use (Sander and Manson 2007, Lake et al. 1998). Viewshed based methodologies allow a range of metrics associated with the characteristics and quality of views to be derived. For example, Lake et al. (2000) and Cavailhès et al. (2009) determined how the visibility of certain landscape elements, such as greenspaces, water and components of built environments affect property prices. Although the computation time strongly depends on model parameters and the computing power available, such methods hold the potential to reduce study costs and subjective categorization of views compared to other methods such as undertaking on-site visits (Paterson and Boyle 2002, Yu et al. 2007).

Virtual city models have particular potential for the enhancement of GIS-based visibility analyses, including viewshed techniques, because they provide a digital representation of the landscape of a real city in three dimensions with high detail levels (Evans et al. 2005). Some publications have recently begun to explore their potential. Yano et al. (2007), for instance, used a virtual city model to undertake viewshed calculations to create a visibility map of cultural objects in the city of Kyoto, Japan. Yu et al. (2007) and He (2007) employed three-dimensional building models to evaluate effect of views on property prices. Using viewshed analysis, the former research also conducted a simulation exercise of a redevelopment project to maximize sea views and assist with the identification of associated premiums on property prices. Yang et al. (2007) extended the concept of viewsheds by showing how virtual city models can be used to implement viewsphere techniques. These better encompass the inclusion of three dimensions in the estimation of visibility. However, to our knowledge, the potential of the models to assess how population exposure to views may be socio-demographically patterned has not been explored, and this forms the focus of our case study which uses the Kyoto virtual city model.

Jones et al. (2009a) defined equity of access to amenities as equal opportunity to use among different socio-demographic groups, and in this work equity of access to views is thus defined as the equal distribution of a view from properties regardless of the socio-demographic characteristics of their residents. For our case study, we employed the two measures of access to views from properties that were suggested by Bateman et al. (2001). Firstly, the expansiveness of the view from properties (i.e. total area of visible land regardless of landscape elements) was investigated. Secondly, we examined equity in access to views of different types of land uses: four scenic amenities (greenspaces, historical buildings, bodies of water, and sacred mountain sites) and two landscape disamenities (factories and roads).

Greenspaces and bodies of water are probably the landscape elements that have been shown to possess the highest visual amenity, with urban greenspaces such as parks (e.g. Luttik 2000), natural vegetation such as trees (e.g. Anderson and Cordell 1988), and bodies of water (e.g. Luttik 2000) consistently found to be positively valued components. We also focused on visibility of valued mountain sites since this is a positive component of Kyoto's landscape (Kyoto City Council, 2007). To evaluate this, locations of Gozan-Okuribi were chosen as visual objects. Gozan-Okuribi are six large bonfires which are lit on the hillsides of five mountains in an ancient ritual to send Buddhist spirits back to the realm of the dead after their annual visit to the world of the living (Yano et al. 2007). This is a famous summer event in Kyoto, and several new apartment buildings are advertised with views of Gozan-Okuribi as one of the advantages (ibid). Compared to more natural settings, relatively few projects have examined how components of constructed environments may be valued, although historical buildings are known to possess positive qualities (e.g. Sasaki et al. 2003). In this research, we thus consider four types of historical buildings: shrines, temples and castles and early modern architectural structures, which are buildings which were designed and built incorporating Western techniques in the 19th century and which are culturally valued in Japan (Yano et al. 2007). For disamenities, industrial areas (e.g. Bateman et al. 2001) and roads (e.g. Cavailhès et al. 2009, Bateman et al. 2001) have been shown to be negatively valued in settings outside Japan, and are therefore focused upon here.

Using the case-study of Kyoto, Japan, this research was undertaken to examine the utility of virtual urban models for the assessment of visual amenity, and to evaluate how access to visual amenity may vary across different populations within the urban environment. The work builds on the existing literature by using a cutting-edge dataset (the "Virtual Kyoto" model) which provides a more complete representation of the complexity of the urban form. It also develops new methodologies to assign measures of visual amenity to large population samples, and by applying these methodologies, it provides new insights into how equitably views may be distributed across different population subgroups. In this paper we firstly describe the study area and the "Virtual Kyoto" model employed before discussing the generation of datasets required for the assessment of views. We then use a sample of 2% of residential properties to present a method for linking view quality scores to population census data. We present an analysis based on this linkage which shows the equity of access to views in Kyoto before concluding with a discussion of the benefits and caveats associated with our approach, as well as the potential policy implications of our findings.

2. Data and research design

2.1. Study area

The case study is set in the city of Kyoto, which is situated in the Kyoto prefecture of Japan. The study area boundaries were defined based on the spatial extent of the virtual city model we used (Figure 6.1). The northeastern ward of Kyoto (called Sakyo ward) was not included in the study area since land use data was not available for this area. Kyoto is a city with the seventh largest population in Japan, and is known as one of the most popular tourist attractions (see Kyoto City Council 2007). Compared to other Japanese cities, a great number of historical buildings still remain, and in 1994 seventeen locations in the city were classified as world heritage sites by UNESCO. The local authority also has been attempting to conserve other landscape elements, such as greenspaces and water bodies (ibid).

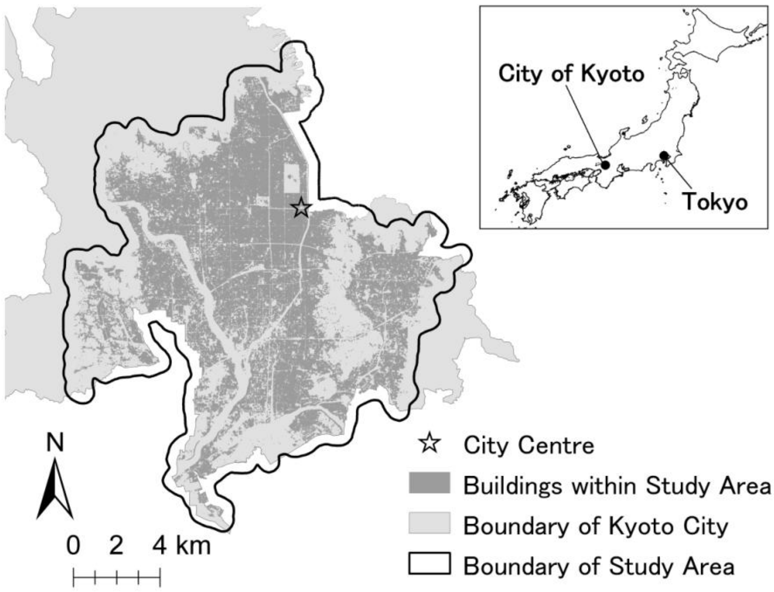

Figure 6.1. The study area in Kyoto city.

2.2. Virtual city model data

This research employed the “Virtual Kyoto” model, which is a Japanese virtual city model developed by the GIS research team at Ritsumeikan University in Kyoto. The production process of Virtual Kyoto is described in detail by Yano et al. (2007), and thus is only briefly recounted here. Table 6.1 details the datasets used for data generation and analysis.

Table 6.1. Details of datasets for the environmental equity analysis

Name	Type	Contents	Publisher	Year
MAPCUBE (Building shape)	Polygon	Building shape and height (scale: 1/2500)	Increment P, co CAD centre, co	2002
MAPCUBE (Elevation)	Point	Elevation of land (horizontal resolution:2.5m) (vertical accuracy:±15cm)	PASCO, co	
Z-Map Town II (Building shape)	Polygon	Use of each building (scale: 1/2500)	Zenrin co., ltd.	2000
Z-Map Town II (Road network)	Line	Road network (scale: 1/2500)		
Digital Map 50m Grid (Elevation)	Point	Elevation of land (horizontal resolution:50m) (vertical accuracy:±7.5m)	Geographical Survey Institute	1986
Digital Map 5000 Land Use Data	Polygon	Land use (scale: 1/5000)	Geographical Survey Institute	2001
Address list of early modern architectural structures	Attribute	Positional data of early modern architectures	Architectural institute of Japan & Kyoto prefectural Board of Education	End of the 90s
Census records (Tabulation for small areas)	Attribute	Population characteristics for small census areas	Ministry of internal affairs and communications	2000

To generate the Virtual Kyoto building model, two different commercially available building shape polygons (i.e. MAPCUBE and Z-Map Town II) were employed. The former is composed of prismatic three-dimensional structure models which were generated from building footprint data and airborne laser profiler data to measure height values at an interval of 2.5m (Yano et al. 2008) (Figure 6.2). Z-Map Town II includes information on the number of stories and the use (for example commercial or residential) of each building. To collect these building attributes, ZENRIN undertook house-to-house surveys within the city of Kyoto.

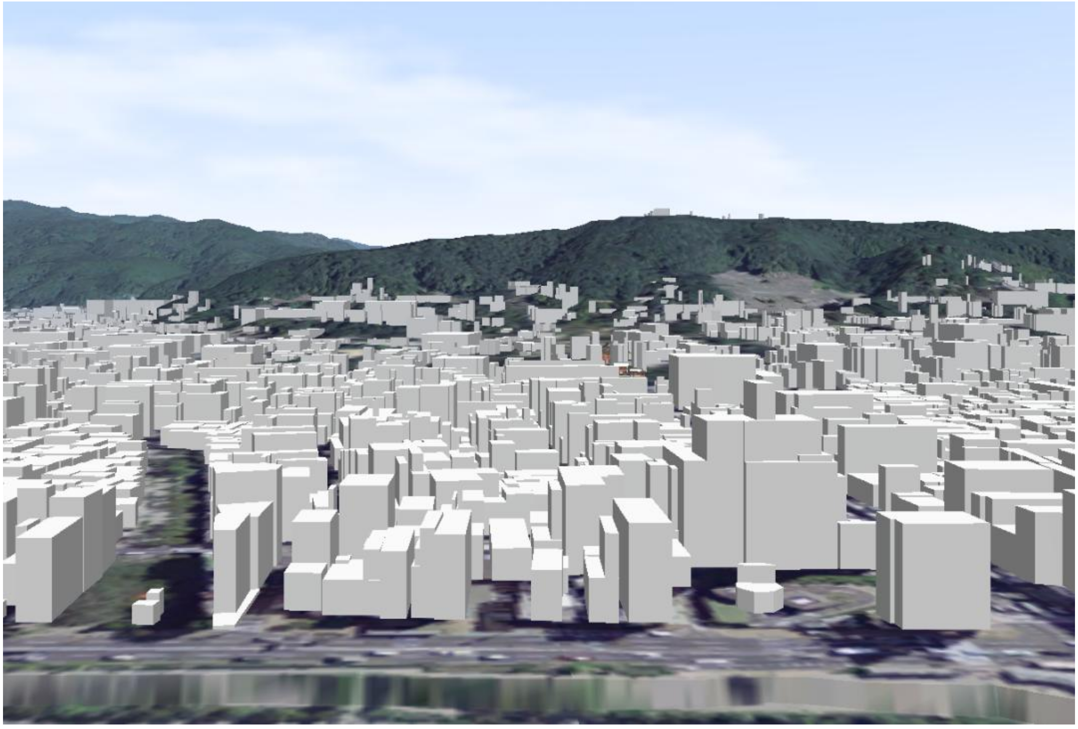

Figure 6.2. Example building shape polygons derived from MAPCUBE data

2.3. Generation of dataset for viewshed calculations

Three types of data were integrated to identify the visibility of objects using viewshed calculations: a Digital Surface Model (DSM), positional data providing the location of observer points, and land use data. In order to generate the building models for the viewshed calculation, MAPCUBE and Z-Map Town II were combined. The shapes of MAPCUBE polygons are detailed and accurate, yet they do not contain information on the building attributes held in Z-Map Town II. To integrate these two sources, building centroids from Z-Map Town II were overlaid on the MAPCUBE polygons. The output data contained information on all the height, the number of stories, and the use of each building (Yano 2006). Based on an attribute stored in Z-Map Town II, each building was identified as being a private residence, shrine, temple, castle, factory, or other structure. Next, using the database obtained, the position of each early modern architectural structure in the study area was identified and the building typologies were updated accordingly.

To generate the DSM used in this analysis, we firstly created a Digital Elevation Model (DEM) using the 'MAPCUBE (elevation)' and 'Digital Map 50m Grid (elevation)' datasets. Both types of data are point based, recording the elevation of the land surface at equally spaced intervals. The former covers the urbanised parts of the city, whilst the latter covers the surrounding mountains. These two sets of points were merged and converted into a raster layer at a 1m horizontal resolution. Next, the building data outlined above was converted into a 1m raster grid, with each raster cell recording the height of the building it fell within. These values were then added to the DEM to generate a 1m resolution DSM of Kyoto city.

Since the focus of this research was on the relationship between population characteristics and access to views, only residential buildings were chosen to determine the positions of observer points. As the location of windows was not known, the horizontal position of the front door of each property was chosen as the location of each observer point. To determine this, each building polygon was split into sidelines, and the front door was assumed to be the midpoint of the sideline closest to the nearest adjacent road depicted in the Z-Map Town II road network. Because of the 1m resolution of the DSM there was the possibility that some observer points may fall within the building boundary. To avoid this, these points were moved 1m away from the assumed front door location of each building.

For each property, a viewshed was computed for two different height levels; the ground floor and top floor of the building (Figure 6.3). The former was calculated from an assumed eye level of 1.6m above the ground. To calculate the latter, information on both the number of floors and the height of each building was used to estimate the eye level of an observer standing on the top floor of the building.

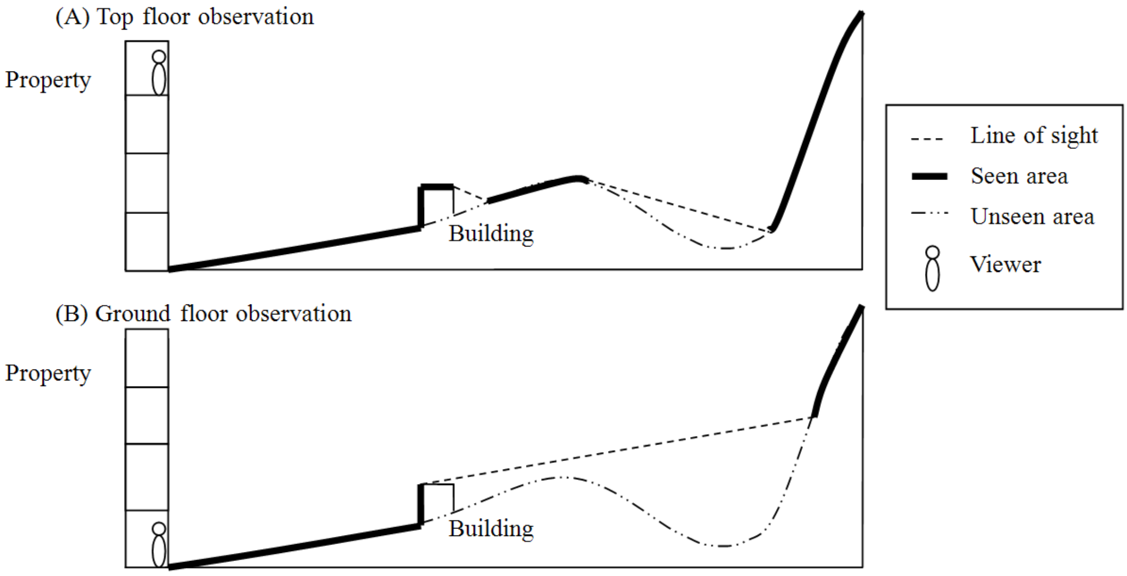

Figure 6.3. The computation of visibility from the ground and top floor

The land use profile of the study area was generated using the combined building shape polygons described above, and the ‘Digital Map 5000 Land Use’ dataset. The latter was generated from aerial photographs and urban maps, and represents a wide variety of land use types from which those used in this analysis were extracted. The land use data was employed to generate a 1m resolution grid indicating the location of the chosen visual amenities and disamenities.

There are over 290,000 residential properties in the study area, and the computational demands of the methodology (several minutes to compute each viewshed on a dual-core machine) meant that it was not possible to calculate visibility scores for each. Therefore, a stratified random sample of 5172 (2% of the total) properties was selected. In order to maximize the heterogeneity of the sample, stratification was based on two variables from the 2000 Japanese Census; the percentage of professional/technical workers and managers (an indicator of affluence level) and the percentage of detached houses (a measure of housing structure) in each small census area in Kyoto. Properties were first allocated to quintiles of the affluence indicator, and were then further stratified in terms of the quintile of the percentage of detached houses in their census area. All properties were therefore categorized into 25 groups, and random sampling was applied to select an equal number of properties from each group for the final sample.

Using the data described above, a viewshed with an output cell size of 1m was calculated from each of the two observer points for each property using the ArcGIS (ESRI Inc.) package. From this a set of visibility scores were generated. Binary viewsheds were computed to identify visible and non-visible cells, and these were then overlaid on the land use data to identify visible amenities or disamenities. Each viewshed was restricted to an angle 90° either side of the perpendicular. To minimize the time required for the viewshed calculation, a maximum distance considered in the view was set according to the trade-off between calculation times and completeness of visibility scores. Lake et al. (1998) and Yu et al. (2007) both used 500 m as the maximum distance considered, as they showed the number of visible cells of the viewshed does not significantly increase when greater distances were used. This value was therefore employed here. For each viewshed the number of visible cells, regardless of the landscape elements viewed, was summed to produce the measure of view expansiveness. The number of visible cells of each land use type was then summed to create a visibility score for each of the landscape elements of interest, as exemplified by Figure 6.4. As the 500 m cut off used is relatively proximal to each property, no distance weighting was applied when considering the contribution of each cell to final visibility scores (see Yu et al. 2007). However, for each sample property, two different view related metrics were computed; the average of the top floor and ground floor scores, and a binary measurement of whether or not each landscape element was visible at all.

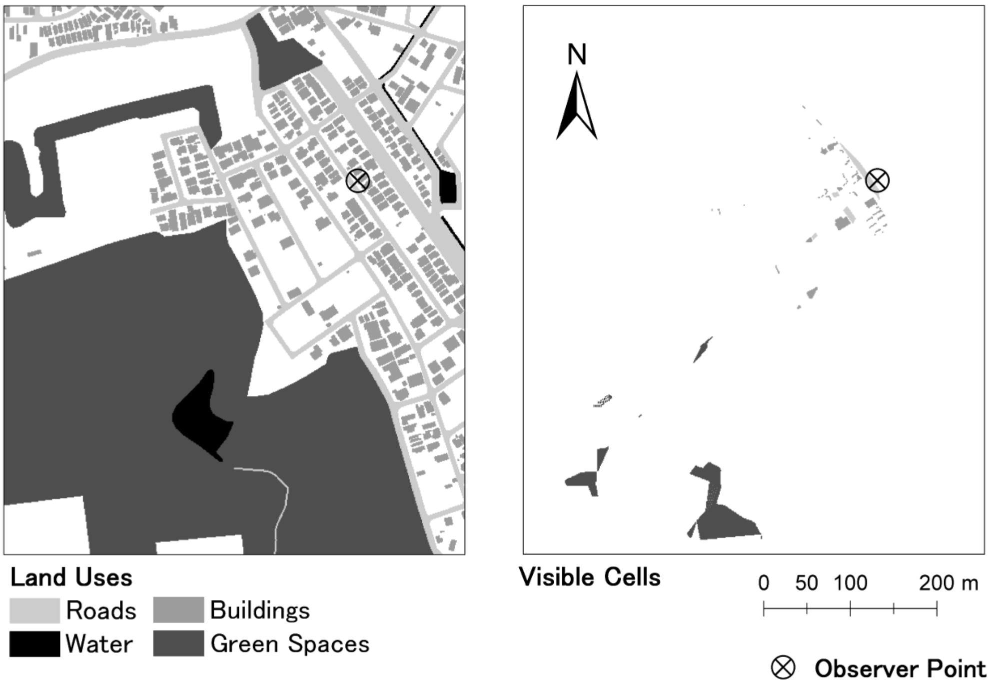

Figure 6.4. Land use data and an example viewshed from the top floor of a property.

The use of a 500 m distance restriction did not allow views of the more distant Gozan-Okuribi to be considered. Therefore a second set of viewsheds were computed to assess views of those features without the distance restriction but with a cruder cell size of 5m. As there are only six Gozan-Okuribi sites surrounding Kyoto, the viewsheds were computed in reverse with the viewer points being the six sites rather than each property in the sample. Because these viewsheds were not computed for individual properties, it was not possible to define a unique viewer height, based on property height for each building. Therefore each property was classified into one of four quartiles based on the distribution of heights of all buildings in the sample. A viewshed from each Gozan-Okuribi location was then computed for each quartile of property height, resulting in 24 viewsheds in total. Visibility was assessed for each property using the viewshed of the corresponding property quartile.

After the viewshed metrics had been computed for each property, they were combined with small area level socio-demographic indicators of the population from the 2000 Japanese Census in order to investigate equity. Age group is frequently used as an indicator in equity analyses (e.g. Brainard et al. 2004, Christie and Fone 2003) because it is an important determinant of a person's vulnerability (Liu, 2001). In particular, older populations may be more susceptible to environmental disamenities due to their poorer health status and decreased mobility and social activity (Sexton et al. 1993). Therefore, the age group analysis in this study focused on pensioners (those 65 years old or more). The Japanese Census does not record incomes but does hold information on occupation and educational level, both of which can be used to approximate the affluence level of each small census area. For this analysis, the percentage of professional and technical workers and managers (high affluence), and also the percentage of residents with either a degree or postgraduate qualification were calculated for each census area and these area measures were used to proxy the affluence of the residents of each property.

2.4. Statistical analysis

In order to examine associations between the population and visual amenity indicators, each of the three social indicators was divided into quartiles, and the mean visibility score for each quartile was computed, along with a test for linear trend in mean scores across the quartiles. An examination of the statistical distribution of visibility scores showed that they were right skewed with many properties having no view of certain landscape features. Therefore a set of logistic regression models were additionally fitted where the odds of being able to view any of each landscape element were computed for each quartile, again with a test for trend.

3. Findings on equity of access to views in Kyoto

Figure 6.5 illustrates spatial relationships between the landscape elements and social indicators in the sample area. In the figure distributions of all social indicators are shown in quartiles. The figure shows how greenspaces tend to be located on the periphery of the city centre, whilst historical buildings and factories are more central. The presence of water bodies is dominated by the Katsura River in the west the Kamo River in the east, and the Uji River in the south of the city. In terms of the social indicators, populations with a high percentage of pensioners tend to be located nearer to the city centre, whilst professional and managerial workers and graduates are more suburban.

Table 6.2 shows the mean expansiveness score and visibility scores for each of the landscape elements across quartiles of the different social indicators. The expansiveness score shows that older groups have less expansive views, but no associations were apparent with the measures of affluence. Trends across the mean values of each landscape element suggest evidence of clear disparities between different age groups, with views of greenspace and bodies of water being disproportionately distributed amongst populations with lower percentages of pensioners. Nevertheless, older communities were found to have generally superior access to views of historical buildings, and had markedly lower exposures to the two scenic disamenities; factories and roads.

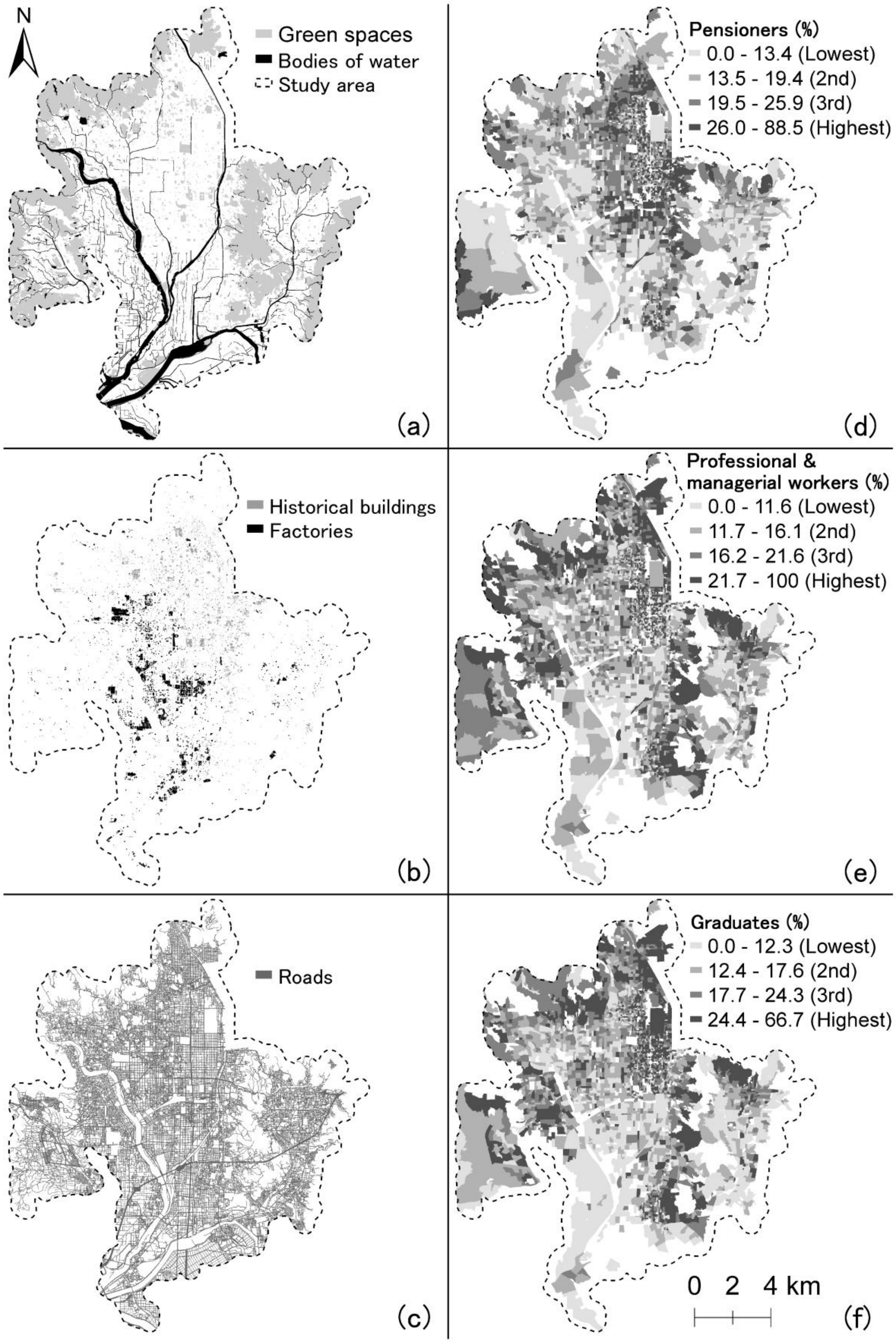

Figure 6.5. The spatial distribution of landscape elements and social indicators: (a) Greenspaces and bodies of water; (b) Historical buildings and factories; (c) Roads; (d) Pensioners (%); (e) Professional & managerial workers (%); and (f) Graduates (%)

Table 6.2. Distribution of visibility scores for each view element considered

Quartiles	Expansiveness Mean (95%CI)	Greenspaces Mean (95%CI)	Historical buildings Mean (95%CI)	Bodies of water Mean (95%CI)	Factories Mean (95%CI)	Roads Mean (95%CI)
Pensioners (%)						
Lowest	23626 (21856 - 25396)	4537 (3812 - 5261)	118 (94 - 141)	1065 (673 - 1456)	435 (302 - 567)	4175 (3841 - 4510)
2nd	16165 (14648 - 17683)	4559 (3795 - 5323)	125 (97 - 153)	1015 (569 - 1462)	172 (130 - 214)	2405 (2167 - 2642)
3rd	13484 (12019 - 14948)	3139 (2502 - 3777)	162 (136 - 188)	757 (361 - 1152)	124 (94 -155)	2424 (2193 - 2654)
Highest	11988 (10662 - 13314)	2835 (2146 - 3524)	213 (180 - 246)	518 (221 - 815)	84 (56 - 113)	2771 (2488 - 3053)
Trend	– **	– **	+ **	– *	– **	– **
Professional and managerial workers (%)						
Lowest	16419 (14651 - 18187)	3065 (2327 - 3804)	110 (89 - 132)	1272 (714 - 1830)	259 (157 - 361)	3007 (2722 - 3291)
2nd	15303 (13814 - 16792)	2924 (2368 - 3481)	111 (91 - 131)	784 (420 - 1147)	273 (187 - 358)	2789 (2527 - 3052)
3rd	15571 (14337 - 16805)	3992 (3326 - 4657)	174 (143 - 205)	596 (374 - 817)	175 (126 - 223)	3074 (2778 - 3369)
Highest	18020 (16373 - 19667)	5095 (4265 - 5925)	222 (186 - 257)	706 (381 - 1030)	111 (75 - 146)	2907 (2642 - 3171)
Trend	+ NS	+ **	+ **	– *	– **	+ NS
Graduates (%)						
Lowest	17696 (15976 - 19415)	3265 (2576 - 3954)	90 (68 - 111)	1481 (890 - 2073)	235 (189 - 282)	2995 (2720 - 3270)
2nd	15999 (14334 - 17663)	3599 (2881 - 4317)	122 (101 - 143)	749 (377 - 1121)	302 (177 - 427)	2876 (2598 - 3154)
3rd	14213 (12940 - 15486)	3866 (3201 - 4532)	168 (137 - 198)	694 (408 - 980)	153 (109 - 197)	2739 (2465 - 3013)
Highest	17401 (15909 - 18892)	4350 (3600 - 5100)	238 (202 - 274)	429 (272 - 586)	127 (84 - 169)	3168 (2886 - 3450)
Trend	– NS	+ *	+ **	– **	– **	+ NS

Lowest Quartile = Least aged / affluent quartile groups
Highest Quartile = Most aged / affluent quartile group
Direction of trend (+ positive – negative)
**: $P < 0.01$ *: $P < 0.05$ NS: No statistical significance

In terms of the two measures of affluence, the findings show statistically significant increases in visibility scores for greenspaces and historical buildings associated with increased affluence, whilst the visibility of factories significantly declines with increased affluence. Visibility scores for views of water also significantly decline with increased affluence.

Analysis of the distribution of visibility scores showed that 48% of the sample properties could not see any greenspaces, 47% could not see historical buildings, 65% could not see bodies of water, and 52% could not see any Gozan-Okuribi. Table 6.3 reports the odds ratios of being able to see any component of each landscape element from properties according to quartiles of the population characteristics. The trends in odds ratios suggest that properties in communities with older residents were less likely to see any greenspace or body of water. Indeed, compared to those in areas with the least, homes in the areas with the highest pensioner populations were half as likely to see at least some greenspace and a fifth as likely to see water, but were more likely to see the amenities of historical buildings and Gozan-Okuribi, and were much less likely to see the two disamenities. More affluent populations were more likely to see greenspaces, historical buildings and Gozan-Okuribi, but less likely to have views of water and factories, although the magnitude of disparities were not as great as those of pensioners. There was evidence that populations with a high proportion of graduates, but not professional and technical workers, were less likely to have a view of some roads.

Table 6.3. Odds ratios (OR) of being able to view any area of each view element considered.

		Greenspaces		Historical buildings		Bodies of water		Gozan-Okuribi		Factories		Roads	
	Quartiles	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Pensioners (%)	Lowest	1		1		1		1		1		1	
	2nd	0.63	0.54 - 0.74	1.24	1.06 - 1.45	0.49	0.42 - 0.57	0.93	0.79 - 1.08	0.54	0.46 - 0.63	0.36	0.19 - 0.67
	3rd	0.52	0.44 - 0.61	1.99	1.70 - 2.33	0.29	0.25 - 0.35	1.22	1.05 - 1.43	0.48	0.41 - 0.56	0.30	0.17 - 0.56
	Highest	0.55	0.47 - 0.64	3.30	2.81 - 3.89	0.19	0.15 - 0.22	1.30	1.12 - 1.52	0.37	0.31 - 0.43	0.20	0.11 - 0.36
	Trend		– **		+ **		– **		+ **		– **		– **
Professional & managerial workers (%)	Lowest	0.61	0.52 - 0.71	0.52	0.44 - 0.60	1.24	1.06 - 1.46	0.69	0.59 - 0.81	3.43	2.88 - 4.08	1.03	0.66 - 1.62
	2nd	0.69	0.59 - 0.81	0.60	0.51 - 0.70	1.00	0.85 - 1.18	0.85	0.73 - 0.99	3.79	3.18 - 4.52	0.97	0.62 - 1.51
	3rd	0.82	0.70 - 0.96	0.68	0.58 - 0.79	0.95	0.81 - 1.12	0.94	0.80- 1.09	2.13	1.78 - 2.54	0.93	0.60 - 1.45
	Highest	1		1		1		1		1		1	
	Trend		+ **		+ **		– **		+ **		– **		– NS
Graduates (%)	Lowest	0.74	0.64 - 0.87	0.39	0.33 - 0.46	1.71	1.46 - 2.01	0.50	0.43 - 0.59	4.59	3.85 - 5.46	2.50	1.50 - 4.19
	2nd	0.78	0.66 - 0.91	0.54	0.46 - 0.63	1.17	0.99 - 1.38	0.73	0.63 - 0.85	3.57	3.00 - 4.25	1.35	0.88 - 2.07
	3rd	0.90	0.77 - 1.05	0.71	0.60 - 0.83	1.10	0.93 - 1.30	0.77	0.66 - 0.90	1.63	1.36 - 1.96	0.96	0.65 - 1.43
	Highest	1		1		1		1		1		1	
	Trend		+ **		+ **		– **		+ **		– **		– **

Lowest Quartile = Least aged / affluent quartile group

Highest Quartile = Most aged / affluent quartile group

Direction of trend (+ positive – negative)

**: P < 0.01 *: P < 0.05 NS: No statistical significance

4. Discussion and conclusion

In this research we have applied a virtual city model to extend the methodologies available for environmental equity studies. In this case study of equity in access to views in Kyoto city, several inequities related to visual amenity were observed. These were particularly sizable when examined against the percentage of pensioners in different areas, and were also generally most substantial when the amenities of greenspaces, historical buildings and water bodies, and the disamenities of factories and roads were considered. The disparities associated with views of Gozan-Okuribi were somewhat smaller, possibly reflecting their location outside the city boundaries.

A particular advantage of using models such as the Virtual Kyoto adopted by this work are that they provide a sufficient level of detail to permit analysis to be undertaken in metropolitan areas where a great number of buildings exist. Many previous applications of viewshed analysis have been set in rural or suburban settings where few buildings are present and hence modeling is simplified (Putra and Yang 2005). Thus the development of the models provides particular promise for studies attempting to better understand environmental inequities amongst urban populations.

There are several caveats to note regarding the data and methodology used in our analysis. Firstly, certain objects that may be relevant to visual amenity were not captured by the data we used. For example, telegraph poles and fences are potential obstacles to views but were not included in the DSM we used. Similarly, although hedges and roadside trees provide elements of urban greenspace (Gao and Asami 2007), the virtual city model did not include them. Secondly, we had no information on the quality of each landscape element. For example, our metric for greenspaces assumed the quality of different greenspace elements was equal. In reality this may not be the case; Garrod and Willis (1992b), for instance, have shown how broad leaf trees are preferred over conifers in a British context. Similar culturally-driven differences in values may also be present in Japan. Likewise we were not able to measure the quality of water in our metric measuring access to views of water bodies. We might expect scenically managed lakes might provide higher levels of visual amenity than, for example, storm drainage channels. Thirdly, in Kyoto there are other landscape amenities which are valued such as traditional wooden houses known as Kyomachiya (Yano et al. 2007). However, these buildings were not focused in this research since the virtual Kyoto model did not specifically identify them for the whole study area.

Whilst our measures of access to views were based on residential locations, individuals will experience different landscape patterns in daily life that are associated with migration patterns for work, recreation, or other domestic activities (Brainard et al. 2002). If data on individual travel patterns were available, further work to investigate the effects of migration on the disparities we observed would be possible. The use of global positioning systems (GPS) to track the migration patterns of individuals (see for example Jones et al. 2009b) may hold promise for this work.

An additional limitation was that computational considerations meant we were forced to use a 5m cell-size for our estimation of Gozan-Okuribi visibility whilst the rest of the metrics were based on a 1m grid, and we were only able to incorporate a cruder consideration of building height, based on quartiles of height across the sample, for this calculation. It may be that our results are sensitive to this cruder resolution, although the fact that the Gozan-Okuribi are located some distance from the properties studied will minimize the impact. Computational considerations also meant that, with the exception of Gozan-Okuribi, we limited our consideration of view elements to those present within a 500 m distance from each property, and we chose not to apply any distance decay parameter to our visibility scores. We made these decisions because 500 m has previously been found to be appropriate in dense urban areas where more distant views are not possible (for example, see Yu et al. 2007). Work in more rural localities suggests that visibility does not decay for objects situated within 1 km of the viewer (for example, Ogburn 2006 and Fisher 1994), although how these rural findings might relate to a more urban context is yet to be determined.

There are a number of improvements that could be made to our analysis with the availability of greater computing power. Firstly we had to sample a relatively small percentage (2%) of properties in order to limit computing times; although we selected our sample to be representative of the wider population, the implications of this are unknown. Computational limitations mean we also restricted our visibility analysis to the ground floor and top floor of each building. These two locations were chosen to present ‘worst’ and ‘best’ case situations, but the resulting metrics may not be representative of views on other floors. Further we set the observer point to be the centre of each property wall, which we assumed to be where the door is situated. This may not be the case, and our computed views may thus differ from those actually experienced because of factors such as the span of the building obscuring nearby features. An alternative to our methodology, which may have overcome some of these limitations, would have been to back-compute viewsheds from each scenic feature, and consequently estimate the percentage of each building visible. A final limitation is that Sakyo ward was excluded from our study area because of the lack of availability of land-use data for it. The population of the ward is predominantly wealthy and it contains\many greenspaces, historical buildings and water bodies. We hypothesize that the magnitude of the inequities we observed may have been greater had Sakyo been included in our analysis.

Our finding of evidence of inequity in visual amenity raises the question as to what remediation measures may be appropriate. A successful framework for the implementation of appropriate measures may have two components to it. Firstly, we suggest that directed placement of scenic amenities such as greenspaces into socially disadvantaged areas may be appropriate. This may be particularly important given the evidence from commentators such as Pastor et al. (2001) that unequal political power between communities can contribute to environmental inequity, whereby socially disadvantaged populations are likely to lack resources to improve the environment of their own community. Hence, re-examination of zoning and planning regulations, in particular with respect to the introduction of parks or greenspaces and programmes for cleaning up water bodies, may have a role to play. Such initiatives may be especially attractive in situations where they can be privately funded by developers.

Secondly, we note however that market mechanisms are another cause of inequity, and they can have the effect of negating the efficacy of planning policy measures (Liu, 2001). For example, Been (1994) discusses how newly cited disamenities reduce land prices in an area, and as a consequence the poor move into affected communities. Conversely, if newly placed environmental amenities increase land prices, there will be a tendency for more affluent populations to move in. To resist these effects of market mechanisms, we suggest income redistribution programmes, such as the provision off rent assistance for deprived people or rent guarantee programmes like those suggested by Nakagawa (2001) for the old, may be appropriate. These should be part of a package of efforts to combat housing discrimination against socially disadvantaged groups.

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Chapter 7
Overall conclusion

1. Introduction

This research thesis has investigated issues of environmental equity in Japan, a country where very little was known about the issue. Although Japan has rich data for equity studies such as various kinds of GIS data, grid-based census records published every five years, and other types of attribute data including the address list of amenities and reports of air quality provided by authorities, few studies were conducted to quantitatively examine environmental equity. This thesis attempted to explore the environmental equity situation in Japan as well as the potential of in-depth GIS models for further research on environmental equity. In this thesis, we demonstrated the existence of environmental inequities in Japanese cities, and the potential of both longitudinal modelling and a virtual city model for further understanding of equity.

Chapter 7 reviews the main findings to draw together the threads of the argument. It also contains limitations, recommendations for further research as well as an overall summary.

2. Main findings

2.1. Environmental equity in Japan

As previously noted, a very limited number of equity studies are available in Japan. However, through this thesis we found evidence of inequities in a range of environmental qualities in Japanese cities. Chapter 3 showed that proximity to hazardous waste facilities is positively associated with percentage of blue collar workers, whilst negatively associated with technical and managerial workers in Yokohama. The test of proximity to environmentally risky facilities may be one of the most frequently conducted equity studies in the international context (Liu 2001, Pearce et al. 2006), and our result concurs with findings of other research conducted outside Japan, such as the US (GAO 1983, Sheppard et al. 1999, Hamilton 1995), Canada (Jerrett et al. 1997) and the UK (Friends of Earth 2001).

On the other hand, in Chapter 3, only very weak disparities in air pollution exposure were evident. The majority of equity studies on air pollution exposure outside Japan found that there is an association between burden of air pollution exposure and low socio-economic status, for example, in the US (Korc 1996), Canada (Jerrett et al. 2001), the UK (Mitchell and Dorling

2003, Brainard et al. 2002), and New Zealand (Pearce et al. 2006). Therefore our result was inconsistent with the international picture. However, our research examined only one sample city, and major urban air pollutants, such as carbon monoxide (CO) and particulate matter (PM) (Fenger 1999), have not yet been tested in the Japanese context. Therefore, further study on equity in air quality may be required to confirm our results.

We investigated socio-demographic distributions of not only environmental risks but also amenities. In Yokohama, there was only weak evidence of inequity in public elementary school accessibility. In comparison with the two environmental qualities above, equity studies of school accessibility are very limited even outside Japan. One of the few examples is a study by Talen (2001), which found significant disparity in school accessibility among children from different socioeconomic groups in the rural areas in the US. Therefore, our finding is not in accordance with her study, but this may be because our focus was overall children, but not disadvantaged children, and furthermore we looked at an urban area where a larger number of schools tend to be located.

In Chapter 4, we observed consistent inequity of park accessibility between four different time points within 18 years in the sample area. Although all cross-sectional, past studies from other countries (e.g. the US and the UK) accord with our result (Jones et al. 2009a, Wolch et al. 2005, Sister et al. 2007). Chapters 5 and 6 also clarified that access to sunlight and views is disproportionately distributed between different affluence levels and age groups in the city of Kyoto. To our knowledge, inequities of these two environmental qualities have not yet been empirically tested even outside Japan, and thus how these two amenities are socio-demographically distributed was not well known before our research. Therefore, these findings may raise important new policy issues in urban planning.

This thesis provides evidence of environmental inequities with respect to the burden of environmental risk and access to several amenities. The results indicate that it is important to develop a specific framework to remedy these inequities in Japan, although other areas in Japan should be tested to confirm our result. Our findings can be a starting point to consider issues of environmental equity in this country. In particular, it is important to remember that social inequity is increasing and an aging society is growing in Japan (Tachibana and Urakawa 2006, Iwata and Nishizawa 2005), and these social trends may magnify the problem of environmental inequity.

2.2. Longitudinal modelling of environmental equity

Most of equity studies are based on cross-sectional approach, and historically those past studies have been contributing to empirically prove existence of environmental inequities and their severity (Mohai 2008). A particular problem of these traditional equity studies is that they capture the 'outcome' of environmental equity at a single time point, but this approach cannot sufficiently identify the process of generating inequity (Boone et al. 2009, Mohai 2008, Pastor et al. 2001, Liu 2001). To build up effective remediation measures, a longitudinal view is essential to test 'which came first' hypotheses: whether the disproportionate distribution of environmental risks/amenities is a result of the unequal sitting process or of the change in population characteristics after siting (Pastor et al. 2001, Boone et al. 2009). A remediation policy based on inappropriate assumptions regarding the cause and generation process of inequity may be just ineffective or costly (Shaikh and Loomis 1999). The number of past longitudinal equity studies is still small (Mohai 2008) and a majority of them focus on distribution of environmental risks, but the time-dependent view of disparity of access to amenity has been largely neglected.

In Chapter 4 we successfully developed longitudinal modelling to test 'which came first' hypotheses to identify the generation process of disparity in access to public parks, one of the most important urban amenities (Boone et al. 2009). Our analysis showed, first, that strong disparity of park accessibility between different affluence levels of communities consistently existed for 18 years in Yokohama. Next, we found that not only parks were disproportionately sited but affluent people moved to environmentally advantaged areas in Yokohama, although their impact on inequity was not large. The hedonic study also identified that a park has the potential to drive up land and property prices which may attract affluent people. We therefore suggested several remedial measures to reduce persistent inequity, such as direct placement of parks in deprived areas and income redistribution programmes. Our modelling and findings could contribute better understanding of equity in amenity accessibility and relevant policy measures.

2.3. Use of virtual city models

Another limitation of past equity studies is that not all environmental features have been captured and incorporated into the framework of environmental equity research. In particular, essential environmental qualities, which need consideration of vertical variation in urban features including building heights, were largely neglected.

As we showed some evidence of disparities, the most important achievement in Chapters 5 and 6 is that we demonstrated virtual city models that are feasible to calculate in terms of both access to sunlight and access to view across large urban areas. Before the development of GIS and virtual urban modelling, these environmental features could not be assessed in a large area, and thus collecting a sufficient number of samples for statistical analyses was extremely difficult. However we have successfully overcome this problem employing spatial analyses with virtual city models. These GIS-based techniques to evaluate sunlight and view can be used for other fields of urban planning, for example, planning of sustainable energy use across a city (see Wiginton et al. 2010) and landscape planning (see Yano et al. 2007).

3. The choice of study area

There are several reasons for choosing two different study areas in this thesis. Yokohama is a more ‘general’ city which has the second largest population in Japan, and it is bordered by Tokyo, the capital city of Japan; thus, this area represents a typical example of a Japanese city in terms of geography, population, and reputation. Therefore, Yokohama was appropriate for investigating equality in the context of frequently argued environmental qualities, such as proximity to environmentally risky facilities, air quality, and accessibilities to schools and public parks.

However, the data for the three-dimensional spatial analyses (i.e. virtual urban model) was more likely to be available in Kyoto; Ritsumeikan University had already generated an intensively organised 3D-GIS / Virtual reality model of Kyoto landscape known as ‘Virtual Kyoto’ (Yano et al. 2007). This highly sophisticated virtual city modelling was more adaptable to our research focus, that is, access to sunlight and views. In addition, Kyoto is a world heritage city with a 1200-year history and well-conserved natural landscapes and historical buildings and thus, this city was a more desirable study area for landscape research in comparison with the other sites including Yokohama.

The obtained results in these two cities cannot be easily generalised for the other Japanese urban areas, but this thesis demonstrated the application of a research framework that could also be employed in other contexts. Furthermore, the importance of case studies on environmental equity should be emphasised since our society is heterogeneous (Liu 2001) and neglecting the unique characteristics of local cities may overshadow important implications for specific areas.

4. Limitations and recommendations for future works

We present several limitations of the data and methodologies in this thesis as well as recommendations for further works. A common caveat across the four analysis chapters is that all of the studies are based on residential locations, but neglected people's migration patterns. Brainard et al. (2002) suggested that people move for work, recreation, or other domestic activities in daily life, and thus, each individual may experience different environmental risks and access to amenities. A complementary approach is to test environmental qualities across workplaces or schools from the environmental equity viewpoint (e.g. Pastor et al. 2002) since people may spend more time in those places. Another and more sophisticated method could be to apply global positioning systems (GPS) to capture individuals' migration patterns (Jones et al. 2009b).

Furthermore, there are some limitations regarding population measures derived from census records. Employing Japanese census records, we used three social indicators (age, job status, and educational qualification) to clarify the socially disadvantaged population, and these are repeatedly mentioned as important population measures for environmental equity studies (e.g. Brainard et al. 2002, Liu 2001). Nevertheless, there may be several other potentially disadvantaged groups which census records do not capture. An example is disabled people. The handicapped population tends to be vulnerable and less mobile, and deprived of good job opportunities (Lichtenstein 1989); therefore, they are another socially disadvantaged group which we did not focus on in this thesis. Tachibanaki (2006) also noted that information about the most economically deprived people, such as the homeless, may not appear in a census. The concern is therefore that a census may be a slightly biased data source to capture population measures, although most equity studies employ it (Liu 2001).

Although one of the research interests in this thesis was to develop GIS-based longitudinal modelling of environmental equity, we demonstrated the longitudinal modelling of park accessibility only, but other environmental features (e.g. siting of waste facilities) have not been tested yet within a time-dependent framework in the Japanese context. However, it should be noted that there are some barriers to conduct longitudinal analyses, and that is why only a limited number of longitudinal equity studies are available in the international context. A difficulty in conducting time-dependent analyses is that old data may not be readily available since they may be lost or not yet digitised (Mohai 2008, Mitchell et al. 1999, Saha and Mohai 2005). For example, in Yokohama, information about where hazardous industrial management facilities were sited is only available from 2006, but data before 2006 were discarded and are no longer available. Alternatively, even if old information is available, the quality may not be as good as that of recent data (Saha and Mohai 2005, Liu 2001).

To examine equity in a range of environmental features from a time-dependent view, both researchers and the authorities require a specific framework to preserve and digitise old data. Rich availability of historical data of both population measures and environmental qualities may encourage more longitudinal studies. This may be particularly important in developing theories which underpin the findings of longitudinal equity studies, since environmental equity theory is still under active development (Pearce et al. 2006, Saha and Mohai 2005). This is not only because researchers have to consider myriad factors which may generate disparity (Saha and Mohai 2005), but also because historical investigation of equity is still limited (Boone et al. 2009).

As our research has shown, virtual city models have excellent potential to generate measures of environmental quality, not only accesses to sunlight and view, but also other environmental qualities such as noise pollution which considers building height (Kurakula and Kuffer 2008), accessibility to evacuation routes both inside and outside buildings from hazards including fires (Thill et al. 2011), and the burden of flood risks under a range of scenarios (Kolbe et al. 2005) are all now possible to examine by the application of virtual urban models. Investigation of socio-demographic distributions of these additional environmental qualities could be a future direction of study.

Nevertheless, a potential limitation of virtual city models may be data availability. For example, one of the building polygon datasets which we used, ‘MAPCUBE’, which is the foundation data of our virtual urban models, is not available for all Japanese urban areas. Currently only 13 main metropolitan cities hold this polygon data, and thus the majority of Japanese cities are not covered. Further, the first year that MAPCUBE was commercially sold was 2002, and thus, this building shape data is not available for years before then. Although we emphasised the importance of longitudinal modelling, at present the longitudinal modelling of access to sunlight or views may thus be feasible only for around an 8-year time frame. This may not be enough to capture significant temporal change in population characteristics.

Another direction for future research could be the accumulation of international studies that better compare environmental equity between countries. Pearce (2006) warned that summarising findings of past studies is difficult since each uses a different research design, including spatial units and measures of environmental risk or access to amenities. To overcome this problem, Kruize et al. (2007) suggested the development of an internationally uniform standard or methodology for comparing environmental quality between different countries. Careful consideration is therefore necessary for constructing appropriate research designs for internationally comparative studies in the future (Pearce 2006, Kruize et al. 2007).

4. Overall summary

This research thesis empirically tested environmental inequities in a range of environmental qualities (two disamenities and four amenities) in Japan, and some evidence of disparities were found. Whilst most equity studies are from the US, very little work has been published in the Japanese context, and thus it is hoped that this thesis has contributed to bridge the geographical biases. It is also hoped that the thesis has demonstrated several methods to better understand environmental equity using GIS modelling approaches.

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