博士論文

Doctoral Thesis

Achieving resilience with urban agriculture in cities: Quantifying vegetable and nutritional self-sufficiency for food security during post-disaster situations in Tokyo, Japan

（都市農業によるレジリエンスの形成：　東京を事例とした災害時における食料安全供給のための蔬菜・栄養の自給率算定）

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ABSTRACT

Over half of the world population lives in urban areas and 60% of these areas are prone to natural disasters. When a disaster occurs, the distribution of food cannot be guaranteed. Conventionally, governments and households prepare rations and emergency food for short-term response (3 days). Such foods consist primarily of designed to provide energy. Most foods in the mid-term (several days to a few weeks) provided by international organizations consist of carbohydrates due to availability and ease of distribution. Previous studies show that the restoration of normal food distribution, in particular that of fresh food products, often takes time; and this has caused survivors to depend on emergency food much longer (several weeks, months, or years) than intended. Post-disaster dietary nutrition studies show that survivors lack several valuable nutrients in their diets causing non-specific health symptoms, gastrointestinal symptoms, and cardiovascular diseases. In search of other nutrient sources, FAO (2012) reported that urban agriculture (UA) is a potential source of dietary nutrition that can be utilized during emergencies. Namely, nutrients in fruits and vegetables help prevent the health issues described in post-disaster studies. The benefits of UA to social, environmental, psychological, and physical health on a day-to-day basis are widely expanded upon in literature. However, self-sufficiency studies are limited and mostly focus on annual food security in developing countries. Also, no study has assessed the contribution of mixed urban and agricultural land use patterns to resilience. Furthermore, no study estimates the availability of UA products throughout the year for their value during emergency events.

This study aims to quantify the potential of urban fruit and vegetable production and their dietary nutrition value for local use during emergencies. It is hypothesized that urban-rural mixed land-uses in cities increase disaster preparedness and resilience to large

earthquakes by providing fresh fruits and vegetables as a source of dietary nutrition in addition to current carbohydrate-heavy emergency foods.

The present research consists of five chapters with each is core focus linked to the research aim: 1) urban agriculture and its characteristics in Japan; 2) identifying farmlands by a spatial analysis, and the spatial distribution of self-sufficiency in the case study Tokyo; 3) estimating production and nutritional self-sufficiency across time in the case of a large earthquake in Nerima ward; 4) integrated discussion and policy implications on different scales of the case studies and their applicability to other cities around the world with similar land uses; 5) conclusions on resilient land use planning and seasonal emergency food as well as practical recommendations to increase resilience through mixed land use planning.

Regarding the methodology, firstly, two professional (vegetable field and orchard) and two hobby farmland types (allotment and experience) were identified through a literature review and field observations in Tokyo. The locations of professional UA were retrieved from the Land use Section of the Tokyo Metropolitan Government (TMG). The hobby UA locations and sizes were documented by type, using three methodological approaches: a) government database, b) aerial photos, and c) spatial data from the TMG (2015). Furthermore, the present case study was divided into a grid structure and a land use classification was conducted in a Geographic Information System to identify four different land use patterns with varied mixtures of land uses. Based on this data, for each grid cell, the total production of UA products was estimated. Due to lack of data availability, the methods to estimate the production for professional UA and hobby UA differed. In the case of professional UA, the data was derived from governmental data and linked with the spatial data. However, no data on hobby UA production was available. Therefore, the estimation was conducted with data derived from a previous study. Tahara et al. (2011) collected the vegetable production per square meter according to type of hobby UA.

Accordingly applied to the present study, the total proportion of consumable professional and hobby UA was utilized to quantify the self-sufficiency of the population based on the recommended intake of fruits and vegetables per capita in Japan. This empirical analysis found 48,773 professional plots covering 54,409,728 m2 and 490 hobby UA plots covering 664,172 m2. The self-sufficiency results varied according to the land use categorization; therefore, typical examples from each category were described and analyzed further in detail with the nutrient self-sufficiency for the population. Everything considered, the median fruit and vegetable self-sufficiency of the grid cells was 4.13%. The median self-sufficiency in the core of urban area was found to be 0% because of the virtual absence of UA. The urban area with more open spaces and urban area with UA was found to be 3% and 18%, respectively. The nature or forestry area was found to be 110% due to low population densities.

Secondly, Nerima ward was selected as an empirical study area because of its relative high density of existing farmlands, because it is one of Tokyo's 23 special wards, and because of its potential based on the results in section one. The production from professional UA and that from hobby UA were estimated according to the method developed in section one. Furthermore, a harvesting table for the Kanto area was developed from literature. This table divided each month into three time periods. The yields of each vegetable were then equally distributed within the harvest periods of each vegetable. Refuse rates of each vegetable were omitted from the production in order to obtain the consumable weight by vegetable. These results were converted into nutritional values obtained from the Tables of Food Composition, and the nutrient content of all vegetables was totaled for each time period. The self-sufficiency of selected nutrients from vegetables was calculated for each farmland type. Nutritional needs were estimated using population statistics and dietary reference intakes by age and gender. Vegetable production amounted 5,660 tons with a weight-based self-sufficiency of 6.18%, which is higher than that in other literature (for example, the 1.7% estimated for the Cleveland case study). The averages in nutritional self-sufficiencies throughout the year from professional and hobby farms varied by nutrient with the highest being vitamin K (6.15%), followed by vitamin C (5.50%), folic acid (5.15%), dietary fiber (1.96%), and potassium (1.82%), vitamin A (1.54%), vitamin B6 (1.54%), vitamin E (1.13%), and calcium (0.96%). The self-sufficiency rate fluctuated through the year according to the harvest seasons of the available crop species.

Thirdly, based on an integrated discussion of the different chapters, three main policy implications can be drawn from the two case studies and results. The first relates to The Productive Green Land Act enacted in 1974 and revised in 1992 that reduced land taxations if a 30-year commitment to agricultural land use were made. In 2022, farmlands under this Act will have fulfilled their commitment and can be transformed into other land uses. The present study highlights the importance of UA in cities and suggests that further commitment be made to its protection. The second relates to Disaster Prevention Cooperation Farmlands. Registered farmlands can be used for evacuation and building of temporary shelters during emergencies. However, currently no means exist for utilization of available crops. The present study found that these could be useful to meet the nutrient needs of survivors. Therefore, it is proposed to allow their harvest during emergencies. The third is about the transformation of other underutilized land uses for UA productive purposes. Tokyo contains a vast number of small-scale vacant lots. Most plots are too small (average size = 840 m2, median = 153 m2) for large-scaled UA, and some are underutilized over long periods of time, particularly in areas with high population densities and limited amount of additional open spaces. Hobby UA can increase resilience by providing populations residing in these areas with evacuation spaces and a fresh supply of nutrients when a natural disaster occurs.

Regarding the conclusion, this research addresses the aforementioned gap in existing literature and concluded that urban-rural mixed land uses in cities contribute to disaster preparedness and resilience of urban populations. Depending on the time of year, urban agriculture provides a considerable amount of vegetables containing valuable nutrients in post-disaster situations for the prevention of health issues reported in post-disaster studies. Utilizing the results of each chapter, a set of practical recommendations is made to increase resilience in cities with high population densities.

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CSA	Community Supported Agriculture
DRR	Disaster Risk Reduction
EBDRR	Ecosystem-Based Disaster Risk Reduction
FAO	Food and Agriculture Organization of the United Nations
MAFF	Ministry of Agriculture, Forestry and Fisheries of Japan
MHLW	The Ministry of Health, Labour and Welfare of Japan
PUA	Peri-urban agriculture
TMG	Tokyo Metropolitan Government
UA	Urban Agriculture
UCA	Urbanization Control Area
UN	United Nations
UPA	Urbanization Promotion Area
WHO	World Health Organization

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1. INTRODUCTION

1.1. Urban agriculture in Japan

In Western countries, modern planning at the dawn of the 20th century defined "urban" as an area where no agriculture is practiced, separating urban and rural lands by location (Mumford, 2002). In Japan, however, farmlands were classified by household ownership, placing urban agriculture (UA) under the jurisdiction of agricultural policies. These urban UA lands are commonly misunderstood as development failures from the Western perspective. In fact, UA lands are so strictly protected from external capital to take over the lands that the number of farmers are declining. Because UA provides valuable services to the city, the system should be modified to address this decline and preserve farmlands.

Farmlands located in urban or urban fringe areas provide ecosystem services (Elmqvist et al., 2015; La Rosa, Barbarossa, Privitera, & Martinico, 2014; Langemeyer, Latkowska, & Gomez-Baggethun, 2016). Abandoned farmlands, however, lack the benefits from these services. By increasing the number of farmers, urban agriculture lands could be conserved and their maintenance secured while restoring the agricultural sector and thus ensuring livable urban environments in Japanese cities (Yokohari & Bolthouse, 2011).

Globally, farm sizes have increased in response to international competition. However, most farmers in urban and urban fringe areas of Japan are unable to follow this trend because of complex terrains and mixed land uses. Therefore, an alternative path must be explored instead.

1.1.1. Urban agriculture and its diverse forms

The term "Urban Agriculture (UA)" stands for agricultural activities practiced in and around urban areas that come in a variety of types and forms. Within the present study, the definition is linked with UA land uses. The first type is professional UA that is intentionally practiced on the fringe of a city. Medieval European cities maintained vegetable gardens and orchards for fresh vegetables and fruits surrounded by city walls and/or moats. Ebenezer Howard, at the dawn of the 20th century, proposed the concept of a "Garden City" surrounded by agricultural gardens planned to be an integral part of the city (Howard & Osborn, 1965). The second is professional UA unintentionally remaining in the city. This refers to professional UA swallowed by an expanding city, as commonly seen around the globe. The third is professional UA intentionally practiced in the city. In medieval Japanese cities including Edo (present-day Tokyo), farmlands cultivated by professional farmers were an intentional part of the city. Human waste was used as fertilizer, and farm produce was consumed by neighboring residents. This small-scaled recycling system made fragmented farmland an integral part of the urban fabric (Hirohara, Yokohari, Kato, & Watanabe, 2002). The fourth type consists of hobby UA and entrepreneurial agricultural businesses that emerged in the city. The main aim of these practices is to provide experiences to urbanites. They are outside the domain of professional industries and regarded as recreational or categorized in the tertiary industry. The fifth type is professional UA with direct, functional relationships with the city through sales of produce to urbanites looking for specific qualities, such as freshness, or additional services. For example, Community Supported Agriculture (CSA) is not necessarily located in or around the city, but maintains functional relationships with the city. Specifically in Japan, the main motivation for urbanites to engage in a CSA contract is in search for trust with the food source and thus have a better connection with the farmer. As such, this introduction describes UA types in Japan. In addition, their limitations and future directions are discussed in an ever changing world.

1.1.2. Contextual characteristics

Globally, croplands are increasing in size because of international competition and mechanization. While this is also true for Japan (9.7% annual growth from 2005 to 2010), average cropland size remain small (2.2 ha) compared to that of Canada (493.1 ha), United States (89.0 ha), United Kingdom (121.2 ha), and France (84.9 ha) in 2010 (OECD, 2016). As an island country of which 67.1% are forests and fields unfit for cultivation and only 12.4% (2010) serving agricultural purposes (Statistics Bureau of Japan, 2016b), land use optimization is a necessary element in both rural and urban planning. During the Edo period (1603-1868), farmland was integrated into cities (Yokohari & Amati, 2005), and residents connected with the farming culture. This phenomenon is still visible today.

Japan is characterized by several contextual phenomena. Firstly, the triple junction of the Pacific, Philippine, and Eurasian plates results in high levels of seismic activity. Natural disasters have made Disaster Risk Reduction (DRR) crucial in land use planning, creating a system that can provide various services, such as evacuation spaces, applied according to needs of the area. Secondly, the country has the highest proportion of seniors (65 years or older) in the world. Of farmers too, 60% were over 65 years old in the year 2010, therefore it could not be guaranteed that they could conduct the manual labor required with agricultural activities in the long-term. Such a *Super-Aging Society* (Muramatsu & Akiyama, 2011) must reinvent its social system in anticipation of associated costs. Thirdly, farmlands are not exempt from high tax rates. Farm households have subdivided and sold portions of farmlands because of a high inheritance tax (55%), keeping only lands they could cultivate without hired help. Simultaneously, high land taxes pushed UA to innovate (higher quality & diversity in crops) rather than up-scaling and mechanizing, resulting in 10% more revenue per square meter compared to rural counterparts (MAFF, 2011). Thus, the contextual situation of Japanese agriculture must be understood as mixture of small-scaled UA and urban areas providing resilience to natural disasters, green spaces for neighboring residents, and fruits & vegetables with added value.

Agriculture in Japan used to be based on the landlord-tenant system (abolished in the aftermath of World War II until 1945) (Falkus, Kim, & Minami, 1999), under which the majority of tenant farm households endured hard labor with meager incomes. Since then, policies have protected farmers from returning to poor tenants by prohibiting major capital from intruding the domain. Although the system was successful, it became difficult for new households to join. The number of agricultural households was some 5.0 million in 1975, but merely 2.5 million (5% of total households) in 2010 and has continued to decrease (Statistics Bureau of Japan, 2016). The situation is even more severe in urban and urban fringe areas. Tokyo had 32,000 farm households in 1975, but merely 13,000 in the year 2010. Although the decent in Tokyo has stabilized since then, the need to adjust the system and make the agricultural sector attractive again for newcomers is clear.

The City Planning Law (1968) divided lands into Urbanization Promotion Areas (UPA) and Urbanization Control Areas (UCA) (Okata & Murayama, 2011). UPA designated land was to be developed within 10 years and taxed under high rates yet the majority has remained agricultural. The Productive Green Land Act (1974) lowered property taxes on remaining agricultural lands provided that farm households maintain them for 30 years. Land that was designated under UCA was already benefiting from low tax rates. The new act provided tax reductions for UCA designated lands and prohibited urban development (excepting farm houses, retail & public facilities), allowing farms to sustain as the third UA type described above. In effect, the creation of UPA and UCA enabled UA lands to persist in Japan's cities and provide multiple services to urbanites.

1.1.3. Benefits of urban agriculture

The majority of the population in Japan (93% in the year 2015) lives in urban areas (The World Bank, 2016) and an increased awareness of climate change, food safety, and food security resulted in appreciation of UA for their ecosystem services (Elmqvist et al., 2015; La Rosa et al., 2014; Langemeyer et al., 2016; Lin, Philpott, & Jha, 2015). For example, one study analyzing the urban heat island effect in Tokyo indicated that paddy field land coverage of more than 30% reduces the temperature by 2°C (Yokohari, Brown, Kato, & Moriyama, 1997). The World Health Organization also recognized the benefits of ecosystem services, recommending a minimum of 9m^2 of green space per capita. As a dense city with 6,169 people per km^2 (Statistics Bureau of Japan, 2016), Tokyo contains 3m^2 of green space per capita (7600 ha in 2010). Although this does not include UA (7900 ha in 2010), UA also provide ecosystem services to the city and comprise a greater area than that of parks (Tokyo Metropolitan Government, 2016a).

Benefits provided by UA are often context-specific and forgotten in modern planning. Japan frequently encounters natural disasters, and farmland conservation contributes to a resilient urban environment. *Disaster prevention cooperation farmlands* (TMG, 2015) were developed to ensure resilience in a way that they provide evacuation spaces in case of a disaster. There are however, more benefits that could be explored, such as the presence of critical dietary nutrients for the community. Social benefits can be observed as well. “Grow your own food” has become a popular hobby amongst retirees, which can help achieve successful aging (Rowe & Kahn, 1987, 1997), as well as with an increasing number of young families valuing UA as an educational platform for their children. Motivations for participating in UA activities include social connection with the community, leisure, and health benefits of growing food (related to the physical activities) (Armstrong, 2000). Beyond production, UA functions as a platform for residents to remain healthy, engaged in the community, or provide evacuation space in case of a large disaster.

However, UA lands only maintain their identity when cultivated. Increasing the number of people cultivating UA lands could restore UA and ensure livable environments in Japanese cities (Yokohari, Amati, Bolthouse, & Kurita, 2010).

1.1.4. New forms emerging

Professional urban farmers, local governments, and entrepreneurial businesses created experience farming as an innovative response to small-scaled plots, aging farmers, aging society, and land abandonment. Experience farming is a mixed form between professional and hobby UA. The land is owned by the professional farmer and he provides experience to hobby users by renting out the land. He also teaches and guides the hobby user throughout the cultivation process according to a planned planting, growing, and harvesting plan (Sioen, Terada, & Yokohari, 2016a; Tahara, Shioyama, Kurita, & Terada, 2011). Experience farming has a coupled benefit of maintaining farmland and connecting farms with the community, optimizing land uses. The disadvantage of a location that did not allow for up scaling turned advantageous as surrounding residents were invited on the farms. Retirees that had commuted to the business district and were previously disengaged from their local community now enjoy neighborly interactions through planting, and harvesting activities that maintain the lands (Fig. 1).

Figure 1. Radish harvesting as a community event on professional farmlands in Nerima ward, Tokyo (by author, 2016).

In contrast to community gardening and allotment gardening in Europe and North America, UA lands in Japan keep their commercial/professional purposes and follow the productive green land act in UPA or *typical* farmland in UCA. In other words, farm households provide experiences as knowledge transfer to urbanites next to their regular farming activities, and in return diversify their income (Shiraishi, 2001). Moreover, one previous study found that experience farms produced higher crop yields (average = 8.45kg/m^2) than allotment farms (average = 4.16 kg/m^2) and professional farmlands (average = 6.24 kg/m^2) (Tahara et al., 2011). One reason can be because of the professional farmers' involvement and hobby farmers growing their crops to sizes beyond market standards. Neighboring residents can also familiarize themselves with the farmers and their lands, as local governments have organized evacuation drills on farmlands. These farmlands play crucial roles in emergency events as farmers are provided with equipment such as gas stoves, emergency food, and water to distribute. Farmers are given this role because of the open space they can provide, a valuable land use for in a densely populated city.

1.1.5. Lessons from European and North-American urban agriculture

The fourth UA type in Europe and North America, such as Kleingartens in Germany and Austria, allotments and community gardens in UK and USA, and colony gardens in Denmark, have a long history and have successfully integrated agriculture in the urban environment (MacNair, 2002). They are not considered professional UA but regarded as recreational activities that benefit participants (Langemeyer et al., 2016). In Japan, complex terrains and mixed land uses in urban areas prevent UA from expanding or intensifying. Therefore, agricultural businesses must seek alternative paths to move forward. By inviting hobby farmers or entrepreneurs to engage with farm households in urban and urban fringe areas as in European and North-American cities, existing farmlands can obtain the necessary human resources (Shiraishi, 2001). These lands could then further contribute to a sustainable living environment with ecosystem services in the form of leisure for an aging society, education for its children, and resilience to re-occurring natural disasters. However, in Japan, the fourth type of UA is still limited. Farmers in Japan can learn from hobby UA organizations and unions in European and North American cities on how to invite urbanites to practice these agricultural activities.

1.1.6. Summary

It was highlighted that distinct types of agriculture can be found in Japanese cities because of their historical, and geographical contexts. Farms in Japan remain dependent on expensive, manual labor because they tend to be small and cannot easily mechanize their production process, calling for the democratization of the agricultural sector. Farmlands in Japanese cities also go beyond mere food production. Firstly, they contribute to the resilience of the city by providing evacuation spaces and diverse food supply in case of disaster. However, empirical evidence on this point is currently lacking. Secondly, as a super-aging society with most residents living in urban and urban fringe areas, there is a potential for farmlands to function as a social platform. Inviting neighboring aged residents and young families, to cultivate and maintain the farmland could address some of the social and demographic issues. Some farm households and entrepreneurial businesses have begun to experiment with such approaches, making skill transfer a greater source of income than crop production. To avoid further land abandonment, which consequentially leads to the loss of context-specific ecosystem services and resilience to natural disasters, the agricultural sector should invite newcomers to cultivate the lands. To increase access to the platform and meet the increasing interest by urbanites, underutilized land uses should be transformed to increase the exposure to green infrastructure in urban areas.

1.2. Research design and description of literature gaps

The present thesis consists of five chapters: 1) urban agriculture and its characteristics in Japan; 2) identifying farmlands by a spatial analysis, and the spatial distribution of self-sufficiency in the case study Tokyo; 3) estimating production and nutritional self-sufficiency across time in the case of a large earthquake in Nerima ward; 4) integrating discussion and policy implications on different scales of the case studies and their applicability to other cities with similar land uses; 5) conclusions on resilient land use planning and seasonal emergency food as shown in Fig. 2.

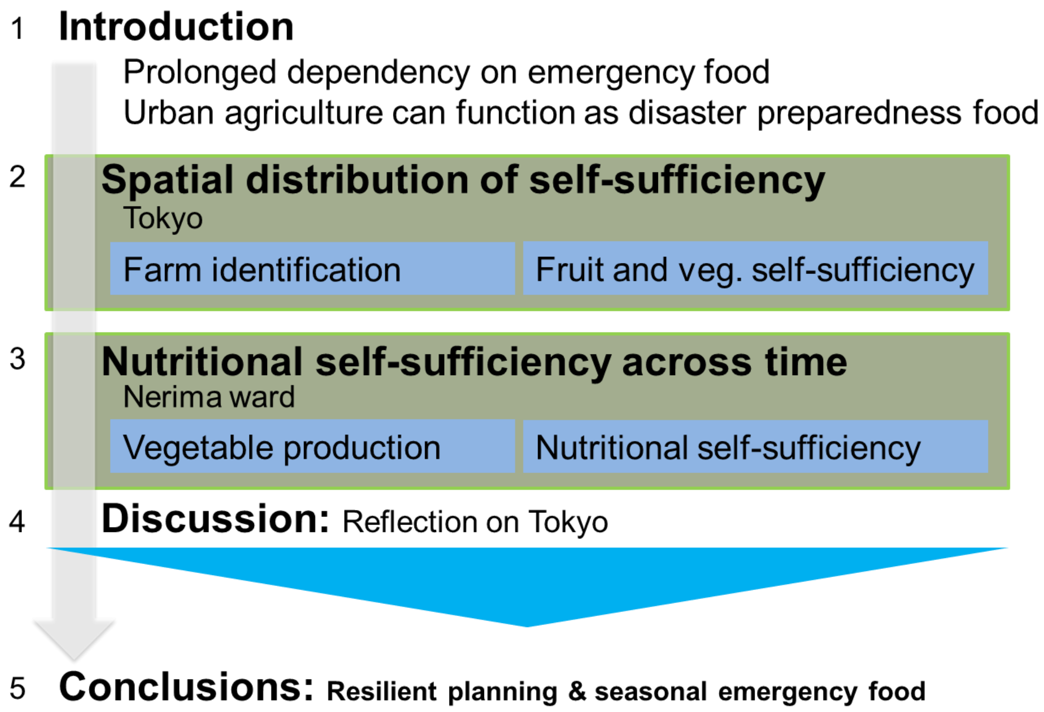


Figure 2. Conceptual approach linking a spatial analysis with neighborhood self-sufficiency for emergency situations.

The case studies for the present study were selected based on the exposure to large earthquakes of major cities in the world. The selected region has the highest risk of large earthquakes in the world (Sundermann, Schelske, & Hausmann, 2014) as shown in Fig. 3. Disaster preparedness has been on the agenda of the Tokyo Metropolitan Government (TMG). It was predicted that the city, which is located in the most earthquake-exposed community of the world, when experiencing a magnitude 7.3 earthquake would kill about 5,600 people, injure 159,000 and destroy 850,000 buildings (TMG, 2012). Most urban systems would be paralyzed in the aftermath of a large earthquake. In such a situation, Tokyo's residents would have to rely on emergency food, bringing with them other consequences, which are addressed throughout the present thesis. Therefore, a self-sufficiency analysis can provide us with the necessary insights on the contribution of UA as disaster preparedness food during such emergency situations.

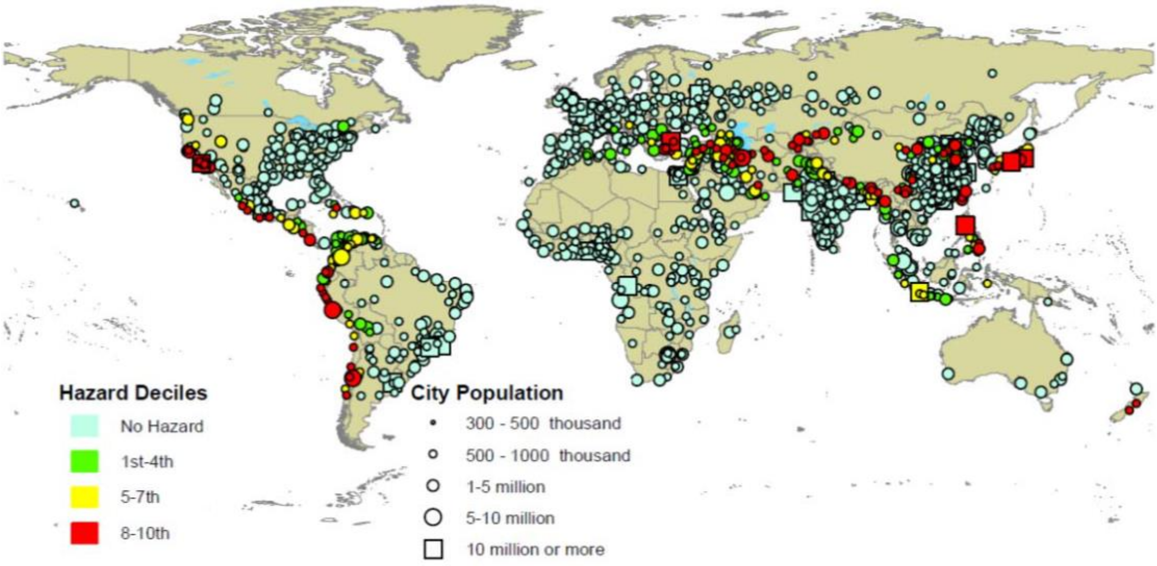


Figure 3. Risk of exposure to earthquakes for cities of the world. Adopted from Gu, Gerland, Pelletier, & Cohen, 2015.

1.2.1. Spatial gap: Self-sufficiency depends on land use patterns

The availability of agricultural products in urban areas depends on the land use pattern, availability of agricultural lands, and population density in that area as shown in chapter 2. Distribution of emergency food and movement of people is restricted in post-disaster situations (Inoue et al., 2014; Nakazawa & Beppu, 2012; Nozue et al., 2014; Tsuboyama-Kasaoka et al., 2014). Previous studies estimated self-sufficiency for an entire city region or a selected area within a city (Grewal & Grewal, 2011; Haberman et al., 2014; Badami & Ramankutty, 2015; Kim, Burnett, & Ghimire, 2015; Rodríguez-Rodríguez et al., 2015). To analyze self-sufficiency on a neighborhood scale and what land use mixture can lead to resilience, a spatial land use pattern analysis should be conducted that can distinguish areas according to self-sufficiency rates and ensures the availability of fresh produce without the need for transportation from external areas (e.g. rural areas surrounding the city) (Fig. 4). This gap is further detailed and addressed in Chapter 2.

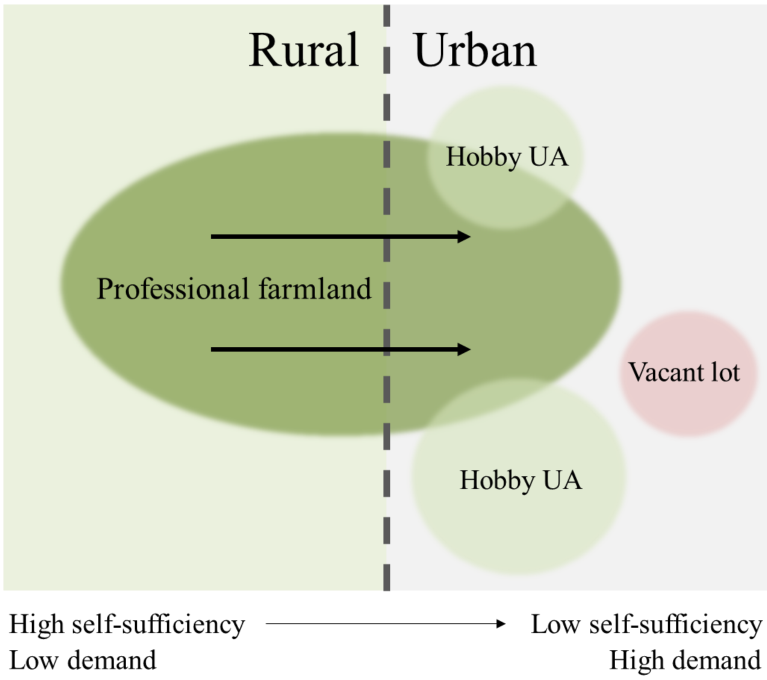


Figure 4. Conceptual diagram of the spatial distribution of different land use patterns. Previous literature assumes a linear correlation between self-sufficiency and the gradient of land use patterns from rural to urban.

In Japan there are several types of UA land uses inside urban area (Tahara et al., 2011; Sioen et al., 2016) and potential to utilize vacant lots to increase self-sufficiency on a local scale for utilization on day-to-day basis and during emergency events.

1.2.2. Time gap: Self-sufficiency varies throughout the time of year

Natural disasters are intractable and impact at random (Altay & Green, 2006), which requires the quantification of UA vegetable production and self-sufficiency throughout the year for mitigating the effects in post-disaster situations. However, previous studies linking agricultural production with dietary nutrition, focused on the yearly self-sufficiency rate for food security purposes. The gap is explained in Fig. 5 in the form of a conceptual diagram that visualizes the random impact of the largest earthquakes in Japan over the past 100 years. The figure also shows two peaks in yield production throughout the year. This gap is further elaborated and addressed in Chapter 3.

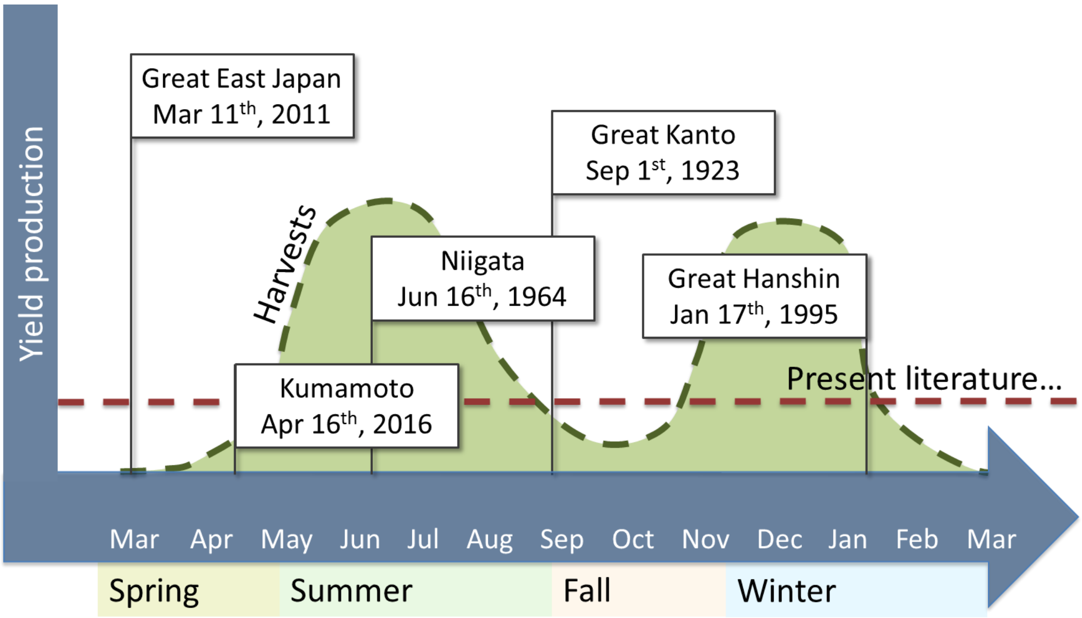


Figure 5. Conceptual visualization of present literature and the impact of great disasters during different times of the year (by author).

1.2.3. Needs gap: Agricultural products and nutrients

Previous studies estimated self-sufficiency of agricultural production on scale of vegetable weight (Grewal & Grewal, 2011; Haberman et al., 2014; Badami & Ramankutty, 2015; Kim, Burnett, & Ghimire, 2015; Rodríguez-Rodríguez et al., 2015). However, post-disaster studies across the world reported the need to supply nutrients to survivors. For example, after the Great East Japan Earthquake on March 11th, 2011, distribution of fresh vegetables, meat, fish, and dairy products with well-balanced proteins and vitamins was difficult (Inoue et al., 2014; Nakazawa & Beppu, 2012; Nozue et al., 2014; Tsuboyama-Kasaoka et al., 2014). In some areas, disasters prior to the earthquake already had diminished rations, exacerbating the lack of nutrients. To make matters worse, the earthquake damaged the main industrial nutrition supplement provider (Amagai et al., 2014), which means that alternative nutrient sources must be made available. This gap is integrated throughout the thesis and addressed in chapters 2 and 3.

1.3. Aim and research questions

This thesis aims to quantify the potential of urban fruit and vegetable production and their dietary nutrition value for local use during emergencies. It is hypothesized that urban-rural mixed land-uses in cities increase disaster preparedness and resilience to large earthquakes by providing fresh fruits and vegetables as a source of dietary nutrition in addition to current carbohydrate-heavy emergency foods during across different times of the year. The following research questions were designed to answer the research goals:

1) How much fruits and vegetables do different types of farmlands produce in Tokyo?

2) What land use pattern is contributing to resilience?

3) How much vegetables and corresponding nutrients can be provided throughout the year?

4) What is the nutrient self-sufficiency of the population throughout the year?

Research questions one and two are addressed in Chapter 2 with the case study of Tokyo. The chapter consists of a comprehensive spatial analysis that categorizes different land uses for the identification of resilient land use patterns. Subsequently, questions three and four are addressed in Chapter 3 through the case study of Nerima ward. The chapter was designed based on the availability of UA products on a municipality scale. Nerima ward was selected as detailed case study because of the results in the first part of the study, the presence of the different UA types, and its high population density in one of Tokyo's 23 special wards. Furthermore, Chapter 4 provides an integrated discussion on the implications of this study on existing land use policies. In addition, suggestions to improve disaster preparedness strategies and emergency responses are made. Finally, the applicability of the findings to other cities with similar land uses are discussed. Chapter 5 provides an overall conclusion of the thesis and brief summary of each chapter.

1.4. Why an urban agriculture self-sufficiency study for post-disaster situations?

There are four main why reasons why a study on UA is conducted on self-sufficiency. Firstly, in the event of an earthquake, areas that were not planned according to formal planning concept may be difficult to reach for emergency relief, especially with short shelf life foods that contain valuable dietary nutrition. Studies showed that even one week after a disaster some areas remain difficult to reach because transportation is down. In that case, for an unforeseeable time, the population in such an area must rely on its own rations as shown above in Figure 4. Post-disaster events found that survivors relied on emergency foods over prolonged periods of time, causing gastrointestinal and cardiovascular diseases (Tsuboyama-Kasaoka et al., 2014). To avoid such diseases and other related symptoms, alternative food sources must be explored and better understood.

Secondly, previous studies showed that despite the high risk of disasters in Japan, a great number of households does not keep rations, does so insufficiently (1-2 days), or only stock beverages, despite the encouragements by the government (Science & Technology Foresight Center, 2012). In order for the government to be able to provide sufficient food and beverages to such households, alternative sources must be explored.

Thirdly, reports show that emergency food had expired and was no longer suitable for consumption. Some households reported that because of the post-disaster-stress, they had forgotten where they stocked their emergency food (Nakazawa & Beppu, 2012). Research conducted in Tohoku after the Great East Japan Earthquake in 2011 showed that emergency foods that were provided contained insufficient vitamin C and vitamin B1 with a self-sufficiency of 72.0% and 81.8%, respectively (Amagai et al., 2014). Such dietary nutrition is commonly found in fruits and vegetables but have been difficult to distribute in emergency events. Broccoli and Japanese Rapeseed especially are vegetables with high contents of vitamin C and again Japanese Rapeseed and Sweet Corn contain the highest vitamin B1 contents (Kagawa, 2016). Exploring the availability from UA can help reduce the shortages in emergency shelters.

Fourthly, existing emergency systems may fail due to the impact of the disaster. During the March 11th earthquake in Japan (2011), the main supplement provider was also damaged, which meant that provisioning of dietary supplements was impossible after the event, which led to dietary related health issues among survivors.

In post-disaster studies, nutrition experts have expressed the need to find alternative sources with sufficient dietary nutrition (Amagai et al., 2014). By analyzing the urban areas holistically, it is evident that there is a pre-existing potential of dietary nutrition. An urban planning analysis shows that there is a considerable number of UA land uses in the city. However, there are no comprehensive and empirical self-sufficiency studies to prove this. Therefore, the present thesis is designed to analyze the potential utilization of pre-existing UA production, which may lead to the application of UA as disaster preparedness food. In this way, UA can functions as a "live ration", and can thus be used on day-to-day basis without the limitations of a short shelf life while increasing resilience to natural disasters. The primary focus of emergency food is to provide energy to survivors. Conducting a self-sufficiency analysis is a common method to understand the availability and demand. Self-sufficiency studies have been practiced in emergency foods as well. According to one study conducted in Iwate prefecture Japan, it was observed that there were sufficient rates of energy (91.8%). In Iwate, there was sufficient protein available with a self-sufficiency of 105.5% (Amagai et al., 2014). Through a cross-comparison of emergency shelters, it was revealed that 23.9% experienced shortages in vegetables and 7.5% experienced shortages in fruits (Tsuboyama-Kasaoka et al., 2014). Further examining the availability of dietary nutrition sourced from UA can lead to optimized emergency provisioning.

2. SPATIAL DISTRIBUTION OF SELF-SUFFICIENCY IN TOKYO

2.1. Introduction

In 2015, the world population reached 7.3 billion people (UN, 2015), of which 54% lived in urban areas. Population projections indicate an increase to 66% by 2050 (United Nations, 2015). With many countries experiencing rapid urbanization and urban areas often facing many complex problems, governments continue searching for sustainable solutions (UN-HABITAT, 2009). Historically, city regions transformed agricultural lands for more economically profitable land uses. In response to this trend, sustainable food systems were integrated into the new urban agenda (UN, 2016a). To meet the needs of this new agenda and other schemes such as the Zero Hunger initiative (UNU, 2015), more research on the current and potential agricultural production in urban areas is needed to identify a variety of sources of products. For this purpose, urban agriculture (UA) has been discussed as one way to address food security in city regions and is defined as any kind of agricultural activity that takes place within or in proximity of an urban area (Smit, Nasr, & Ratta, 2001). UA farmers specialize in small-scaled practices that provide greater diversity and fresher crops compared to those of rural farmers (Orsini et al., 2013). When focusing on fruit and vegetable production, the practicing UA has already been proven to overcome many urban challenges (such as food security, access to fresh food, resilience, dietary diversity, nutrition intake, social interactions, heat island effect, and a source of income for urban poor (Warren, Hawkesworth, & Knai, 2015a)). UA can be practiced on lands of any size or shape (Mogk, Kwiatkowski, & Weindorf, 2011), making it a land use that can easily be adapted on underutilized land such as vacant lands that are often unsuitable for other purposes. UA can also be practiced on lands accompanied with flood or earthquake risks (De Zeeuw, Van Veenhuizen, & Dubbeling, 2011). These benefits show that UA contributes to the sustainability of urban areas, especially by developing underutilized land.

Urban areas must secure a stable food supply for their populations because more than 60% of urban areas are prone to earthquakes, floods, and tropical cyclones, which can affect the supply from other areas. Increasing resilience resulting from preparedness and adaptation strategies has been a fundamental agenda item for cities to address, especially in relation to the social, environmental, and economic infrastructure (UN-Habitat, 2016). The international community has already recommended the integration of such strategies. For example, the Hyogo Framework for Action aims to integrate adaptation and preparedness strategies into contemporary planning. It was recommended that better land-use planning and the integration of sustainable use and management of ecosystems could improve Disaster Risk Reduction (DRR) (UNISDR, 2005). Additionally, in 2015 the Sendai Framework for Disaster Risk Reduction recommended increasing public and private investments for DRR strategies (UNISDR, 2015). The combination of ecosystem management and DRR was also developed in various forms and practices (Travers et al., 2013). This led to the development of Ecosystem-Based Disaster Risk Reduction (EBDRR) (UNEP & CNRD, 2014). EBDRR has proven to be a cost-effective method for mitigating the impacts caused by natural disasters and presents effective strategies for increasing resilience through the provision of food, water, and building materials (Sudmeier-Rieux & Ash, 2009; UNEP & CNRD, 2014). UA is one such system that can augment EBDRR. For example, in Japan a country that is prone to natural disasters and has cities designed with high population densities, narrow roads, and complex utility systems the government has developed a system that solicits UA farmers to register their lands as disaster prevention cooperation farmlands (Komatsu & Kitazawa, 2010). Registered farmers agree to have affected populations temporarily evacuate to their farmlands, and permit the construction of temporary shelters where emergency food is distributed. This is an EBDRR strategy that contributes to overcoming the temporary lack of food after a natural disaster. Sustainability science has been at the frontline of solving such complex issues caused by the impact of natural disasters on cities. Analyzing problems holistically using a sustainability science approach acknowledges problems within social, environmental, and economic dimensions alike, rather than focusing on physical morphological issues of the urban area alone (Sioen, Terada, & Yokohari, 2016b). Using this approach for natural disasters in megacities results in a broader set of methodological opportunities. This approach promotes further integration of agricultural land uses in new and established cities as a disaster preparedness method, with the help of EBDRR strategies.

UA activities have also been linked to healthy lifestyles on a day-to-day basis. The increased intake of fresh fruits and vegetables has been linked to the prevention of cardiovascular diseases, cancer, and other dietary-related health problems (Slavin & Lloyd, 2012). Depending on the socio-cultural status of the city, many people eat unhealthy "junk food" (Deelstra & Girardet, 2000) and linkages between lifestyle habits and health have been reported in several food studies (e.g. food dessert studies) (Beaulac, Kristjansson, & Cummins, 2009; Hendrickson, Smith, & Eikenberry, 2006). A study conducted in New York City found that participation in Community Supported Agriculture increased people's vegetable consumption. Furthermore, it was reported that participants had positive dietary pattern changes and focused on local production as well as seasonal varieties (Wilkins, Farrell, & Rangarajan, 2015). Also, participation in UA was linked with increases in physical activity. A study conducted in the Netherlands showed that participants from all age categories experienced this increase with the greatest overall health benefits being found in older participants (van den Berg et al., 2010). The health benefits of UA activities have also been linked with natural disasters because of access to fresh produce (FAO, 2016) and dietary nutrition (Sioen et al., 2017).

In an attempt to quantify how UA can help food security, more evidence-based spatial distribution studies in combination with self-sufficiency measurements in city regions are required. Achieving self-sufficiency in such regions depends significantly on the yield production and availability from agricultural land uses (Grewal & Grewal, 2011; Kim et al., 2015; Sioen et al., 2016a). Previous studies in city regions that were struck by a large earthquake reported the need for more nutritious diets (The World Bank, 2010). The recovery of the normal distribution network could take weeks or even months to recover when road infrastructure is heavily damaged. With an increasing number of cities growing exponentially, the number of people affected is potentially larger than that in a rural area with more open spaces (UN-Habitat & ESCAP, 2015). Therefore, health issues can occur among a proportion of the population. Consequently, understanding what UA can contribute in terms of fruits and vegetables on a local scale in different parts of the city region is needed.

The present chapter aims to identify the spatial distribution of different UA types in the urban area of Tokyo. The UA contributions to neighborhood self-sufficiency are calculated and infer policy implications for the protection of UA are proposed to increase the transformation practices of unutilized land for more productive purposes. The results support the increase in UA DRR practices for resilience. In particular, the presence of UA land uses in city regions prone to natural disasters may provide fruit and vegetables to combat residents' nutrition deficiencies, especially if products from sources outside the region can no longer be provided. The rationale for conducting this research is that previous studies have highlighted the lack of evidence for the utilization of fruits and vegetable production from UA and the contribution to nutritious diets. Understanding the benefits of mixed land uses in city regions may result in the adaptation of policies for different city regions around the world seeking to maximize their resilience strategies for future challenges.

2.2. Materials and methods

This study is designed with a mixed-method approach combining spatial data and quantifications in four Steps: 1) spatial analysis was conducted to identify the farmlands in the study area, 2) grid structure was applied to the case study and a land use categorization was made to identify different land use patterns, 3) production and self-sufficiency based on the population was quantified for each grid cell, and 4) nutritional self-sufficiency of a selection of nutrients was conducted. Furthermore, the discussion section is designed around the land uses and the corresponding results from the other sections in the study.

2.2.1. Empirical case study

The Tokyo Metropolitan Area, one of the world's 35 large megacities (a city with more than 10 million inhabitants) (UN, 2016), is located in the most earthquake-exposed community of the world (Sundermann et al., 2014). Tokyo prefecture has a population of 13.51 million people and a population density of 6,168 people per km^2. Residential migration to the city has caused a reported increase in the population of 2.7% from the year 2010 to 2015 (Statistics Bureau of Japan Ministry of Internal Affairs and Communications, 2016b). The city has a history of large earthquakes with devastating impact. The Metropolitan Government invests many resources into the preparedness and predictions of the impact of such events. A simulation predicted that a magnitude 7.3 earthquake under Tokyo Bay North Area would kill approximately 9,700 people, injure 147,600 and destroy 304,300 buildings. There would be some 3,390,000 evacuees by the next day, and in total 5,170,000 people would be isolated (TMG, 2016b). The impact of such magnitude shows that food distribution is an important factor in the emergency preparedness and response. Because UA has been a fundamental part of the Tokyo city region since the Edo period (1603–1868), where samurai households maintained their own vegetable gardens (Brown, 2009), there is a pre-existing potential of providing food for the affected populations. However, no studies have incorporated the different land use patterns of the city and their corresponding self-sufficiency from UA considering the different land use patterns in Tokyo. Despite a high population density, the Census of Agriculture and Forestry (2015) reported that there are 11,222 farm households (Statistics Bureau, 2016b) farming a total of 71.30 km^2 of UA lands. Of those lands, 68.60 km^2 are non-paddy fields and 2.77 km^2 are paddy fields (Statistics Bureau of Japan Ministry of Internal Affairs and Communications, 2016b), which hold potential for food security during emergency situations as previously described. In the present study, island municipalities were excluded because of their different socio-cultural and economic conditions. The study was conducted in the remaining 53 municipalities totaling 1,778.09 km^2 (TMG, 2016a). The study was conducted in the remaining 53 municipalities totaling 1,778.09km^2 (TMG, 2016a) as shown in Appendix A.

2.2.2. Step 1: Identification of farmlands

Different UA land uses were selected based on literature studies and field observations (2015-2016). The selection was categorized according to professional and hobby UA. Professional UA was previously documented in literature and governmental statistics. However, there was no pre-existing data on hobby UA. Having a distinction between the UA types was considered important for the present study because each type has its own techniques, choices in crops, and engagement by the farmer (Tahara et al., 2011) resulting in different yields, consequently influencing self-sufficiency rates. In Tokyo, four types of UA were identified for the production of fruits and vegetables as shown in Table 1 (Sioen et al., 2016a; Tahara et al., 2011).

Table 1. Description of selected land use types and their visual characteristics

No.	Producer	Name of land use type	**Description** (MacNair, 2002; Shiraishi, 2001; Sioen et al., 2016a; Tahara et al., 2011)	Visual characteristics
1	**Professional**	Vegetable field (TMG, 2016a) *	Vegetable production similar to that of rural farmers but located in urban area	Field with a limited type of crops planted in long rows
2		Orchard (TMG, 2016a) *	Fruit production from trees by professionals	Field with trees planted over regular distances
3	**Hobby**	Allotment (Sioen et al., 2016a; Tahara et al., 2011)	Land owner (e.g. government, private, farmer) rents out a plot of land to hobby farmers for the production of a variety of vegetables	Subdivided field of mostly rectangular small plots with a high variety of crops within each plot. No continuity in design with neighboring plots
4		Experience (Sioen et al., 2016a; Tahara et al., 2011)	Cultivation by hobby farmer under guidance of professionals for a selection of vegetables	Subdivided field with rectangular designed plots that have regular sizes and that contain a homogenous planting of crops similar over all individual plots
5	**Others (potential)**	Stable vacant lot (TMG, 2016a) *	A long-term vacant lot. This is a vacant lot that has not been changed from another land use since the previous land use survey conducted by the TM	Vacant field that serves as open space. Each vacant lot has different visual characteristics such as temporary use as parking space, grassland, etc.

* Professional UA (vegetable fields and orchards) and stable vacant lots were derived from the land use section of The Tokyo Metropolitan Government.

2.2.2.1. Current urban agricultural land use

Professional UA land uses have been documented by the land use section of the Tokyo Metropolitan Government (TMG) (TMG, 2016a) and are updated every five years. However, hobby UA data is not documented by TMG. The dataset on professional UA (vegetable fields and orchards) was retrieved (2015) and primary data of the spatial locations and areas of hobby UA types was developed in the present study. This was conducted according to the method described by Sioen et al. (Sioen et al., 2016a), updated, and refined according to the latest satellite imagery (2016) and objective of the present study.

Firstly, online hobby farm databases of each municipality were accessed in order to retrieve their locations. In total 46 of 53 municipalities had an official database, of which 27 listed their allotment farms and 19 their experience farms. The location of each farm retrieved from the databases was then identified and documented with Google Earth Pro (ver. 7.1.8) satellite imagery to give an up to data accuracy about the location and characteristics. Each type has their own characteristics. Experience farms are owned by professionals and grown by hobby farmers, resulting in plots with similar crops and patterns. Allotment farms are rented by hobby farmers; however, because there is no guidance by professionals, no homogenous visual pattern can be identified. They have a disordered appearance due to the high diversity of crop combinations.

Next, an accuracy assessment was conducted confirming the existence and type of farm by utilizing Google Street View (Sioen et al., 2016a). When the location of the farm was not detailed enough or the location could not be confirmed, the surrounding area was visually scanned and nearby plots were analyzed according to the criteria set in the visual description of Table 1.

Secondly, identification of the non-registered hobby UA was conducted with the help of a 1 km^2 grid structure that was drawn over the case study area. The satellite imagery inside each grid cell was then carefully scanned for remaining farms and their locations documented and assessed as detailed in the first step.

Thirdly, the locations were superimposed over the governmental UA land use data. To improve the accuracy, their spatial characteristics were shaped according to the plot characteristics of the dataset and given a separate identification code. What resulted was situation A: hobby UA overlaying professional agricultural land uses; and Situation B: hobby UA located on vacant lands or other land uses. In Situation A, the identification code of the existing land use data set was modified to a hobby UA type. In Situation B, a new polygon with a corresponding identification code was added to the existing shapefile. Finally, all UA types were combined into one shapefile that had corresponding codes identifying the type of UA. This was then utilized for land use categorization and production estimates as detailed in Step 2.

2.2.2.2. Potential for urban agricultural land use

Vacant land was identified as a land use that is unutilized in comparison to other land uses in Tokyo. A previous study in Oakland, California indicated the potential of vacant land to be utilized for UA purposes (McClintock et al., 2013). Additionally, previous self-sufficiency studies utilized vacant lots in their scenarios (Grewal & Grewal, 2011; Haberman et al., 2014; Hara et al., 2013). However, in Tokyo, many vacant lands are currently in used as parking areas or other undocumented land uses. Also, they include temporary vacant lands. Therefore, for the development of the potential scenario in the present study, a selection of stable vacant lands was made. To do so, the shapefile was retrieved from the Land Use Section of TMG (TMG, 2016a). Stable vacant lands were identified with the attribute table of the shapefile. Namely, polygons in the shapefile that were modified from the previous land use survey (2010) received a number indicating the land use modification. Only the polygons that had not been modified were selected for the estimation of potential UA land uses in the present study as it ensures their long-term vacancy.

2.2.3. Step 2: Land use categorization

Duany et al. (2012) described the gradient of the city from urban core to the nature zone. Each zone was described based on its corresponding types of agricultural land use patterns and mixtures in land use. The theory was adapted and modified for the present case study to enable a land use pattern analysis of the city region.

To do so, the land use dominance in the present study was analyzed to classify the different land use patterns. Furthermore, the presence of farmlands was analyzed within those patterns because the aim is to estimate the self-sufficiency from present farmlands in contrast to the potential from other land uses. These land use patterns were developed by measuring the area of certain land uses: 1) farmlands as developed in Step one; 2) forests; 3) open spaces e.g. parks, vacant lands; and 4) urban land uses. Road infrastructure and water bodies were excluded from the analysis as these can have either urban or rural characteristics. Similarly, open spaces can be found in the urban areas as well as the rural areas, therefore, these were analyzed separately. The definitions of the patterns for the present study are as follows:

Type A is dominated by urban land uses and does not contain farmlands. This land use pattern is mostly found in the urban core of the city consists of planned residential houses, condominiums, or office buildings. Type B is dominated by urban land uses and contains farmlands. This land use pattern has similarities to the previous type but is mostly unplanned scattered development with a great variety of different land uses mixed together. Type C is dominated by open spaces and does not contain farmlands. This category is mainly found in areas with parks, vacant lands, or fields, which can be found in both urban and rural areas. The fields are mostly found along river banks that enter the city from neighboring prefectures. Also, a lower population density can be observed compared to Type A and Type B. Type D is dominated by open spaces and contains farmlands. Other than the presence of farmlands this category is similar to Type C. Type E is dominated by farmland and contains urban land uses. This can be considered as rural area, thus not a core focus of the present study on UA. Type F is dominated by forest and does not contain farmland. This type is mostly located in the hilly area of Western Tokyo and has a very low population density or in some cases, no population. Type G is dominated by forest and contains farmland. This type can also be described as Satoyama, a socio cultural production landscape with very low or no population density (Takeuchi, 2010).

Each type was systematically analyzed in the city region of Tokyo to identify the land use patterns and mixtures in land uses. To do so, a grid structure (1x1km) was superimposed over the case study area, equally dividing it into sub-areas. The grid cells covering neighboring prefectures were excluded because while land use policies in Japan are drawn on the macro level by the national government, they are interpreted on the prefectural and municipal levels. This meant that local differences could have affected the land use patterns. A total of 1,480 individual grid cells remained. Within the grid cells, the number of plots and total land area of each UA type was collected. Based on the location of the center points, each plot was given the identification code of the grid cell it was located in. The total area for each UA type and number of individual plots was then calculated in each grid cell. Furthermore, the developed data was utilized for the classification according to the land use pattern definitions described in this section above.

2.2.4. Step 3: Reference consumption and production

The reference consumption of the population, UA production, and corresponding self-sufficiency were quantified within each grid cell developed in Step two.

2.2.4.1. Reference consumption of fruits and vegetables

The reference consumption of the nighttime population in each grid cell was estimated. The reference consumption is defined as the recommended intake of fruits and vegetables multiplied by the population. The targeted per capita daily intake of fruits and vegetables was set at 350g by the Ministry of Health Labour and Welfare of Japan (2016) and used to determine the reference intake of the population in each grid cell. The population in each grid cell was available from the land use section of TMG (2016a).

2.2.4.2. Nutritional reference consumption

The nutritional reference consumption was estimated with the latest data on the daily dietary reference intake for Japan (2015) was retrieved from the Japanese Ministry of Health Labour and Welfare (2015). The recommended dietary allowance was chosen, or if unknown, the adequate intake of the selected nutrients by gender (MHLW, 2015) as shown in Table 2. The population in each grid cell was also retrieved as described in Step Three. Because the population data of the grid cells excluded age, the estimation was conducted with the age group that has the highest intake of nutrients, namely adult between 30 and 49 years old (MHLW, 2015). Depending on the nutrient, younger populations would have required less intake, meaning that the present study is still an underestimation of the actual self-sufficiency. Next, the total requirements for the remaining nutrients were calculated for each gender by multiplying the reference intakes for Japan with the population residing in a grid cell.

Table 2. Selected per capita mean daily reference intakes of selected nutrients (MHLW, 2015)

Nutrient	Male	Female
Vitamin A [μg]	900	700
Vitamin K [μg]	150	150
Vitamin C [mg]	100	100

2.2.4.3. Production

The focus on the production of fruits and vegetables varies according to the municipalities because of historical, practical, and cultural factors. Previous studies with spatial production estimations assumed a homogeneous production in each region. The yields of professional UA were estimated based on governmental survey data available for each municipality. To date, the authors found only one study (in Japanese) documenting the production of the two hobby UA types. Therefore, to determine the production yield for each UA plot, the methodology was divided according to professional and hobby UA:

Professional UA

Every five years TMG conducts an Agricultural Products Production Survey in the municipalities that have professional UA (TMG, 2015b). The survey documents the area [are] and production [ton] of fruit and vegetables of professional farms over a one-year period. The latest data (2015) documenting UA activity in 40 out of 53 selected municipalities was retrieved. The results of this data set [ton] were then equally spread over the UA area in each municipality. This showed that the total production per vegetable varied in each municipality.

The harvest for each professional UA type within each grid cell was calculated by multiplying the area per type of UA plot with its corresponding yield factor according to the municipality in which it was located. To obtain the harvest in the municipalities not covered by the survey (13 out of 53), the average yield per fruit or vegetable product was utilized. These averages were then multiplied by the area of each professional UA type in each grid cell as shown in Appendix B.

Hobby UA

A previous study conducted by Tahara et al. (2011) quantified the production of vegetables in the two hobby UA types in the Tokyo Metropolitan Area over a one-year period. The study randomly selected five allotment plots in Inagi, Chiba and five experience plots in Nerima, Tokyo, of which the participants were asked to record weights of each harvest over a one year time period. The results, were retrieved by specifying the types of vegetables. Between the different users of each type of UA, the production did not vary significantly as shown in Figure 6. However, a range in the results of allotment UA was observed. The users in experience farms were under the strict guidance of a professional farmer and harvest schedule, which meant a similar harvest for each hobby user. Different scenarios for the present study are possible by using the ideal case results, the average, or the least ideal. However, hobby UA has only a minor influence on the total UA production in the city. Therefore, the average production per square meter and UA type were utilized for the present study as detailed in Appendix A. To estimate the total hobby UA production by grid cell, the average yield per square meter of each type of land was multiplied by the area of that type.

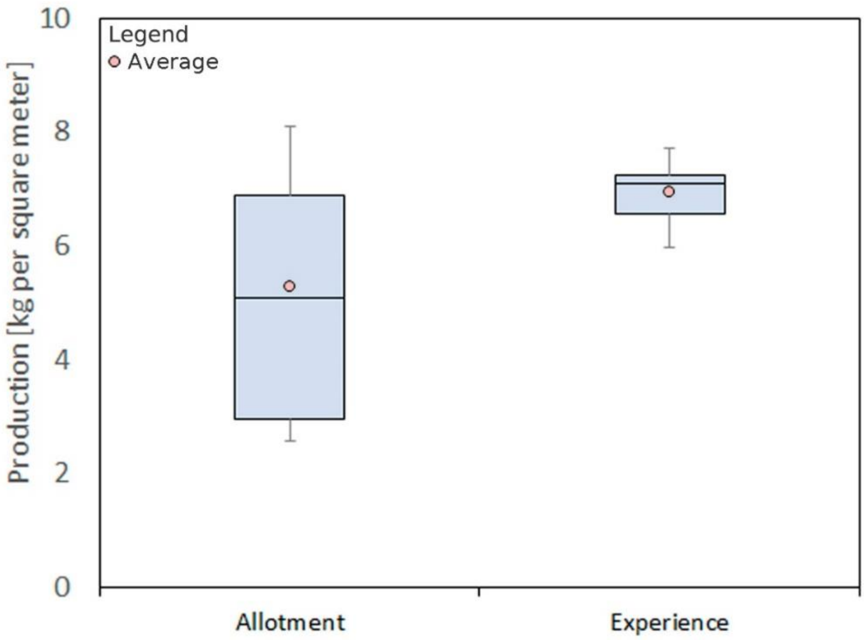


Figure 6. Yield per square meter of hobby UA in previous study (n = 5 per type) (Tahara et al., 2011).

Finally, the results of professional and hobby UA were combined providing an estimation of the total harvest in each grid cell. The total harvest (H) per fruit and vegetable (i) for grid cell (l) was estimated by combining the harvest from professional (p) and hobby farms (h) as follows,

$$H^{i,l} = \sum_{p} Y_{p}^{i,l} A_{p}^{i,l} + \sum_{h} x_{h}^{i} Y_{h}^{i,l} A_{h}^{i} \quad (1)$$

where:

$A_{*}^{i,l}$ is the field area per farm type for fruit or vegetable (i) in grid cell (l) [m^2],

$Y_{*}^{i,l}$ is the yield per farm type for fruit vegetable (i) in grid cell (l) [kg/m^2],

x_{h}^{i} is the vegetable production percentage for hobby farms [-].

(*) is to be replaced by (p) or (h).

The yield factors produced for each municipality are listed in Appendix B.

2.2.5. Step 4: Self-sufficiency of fruits and vegetables

The outcome of the previous section show the harvests of fruits and vegetables for each grid cell. However, before consumption, fruits and vegetables are cleaned and the parts not suitable for consumption hereafter referred to as the refuse rate were removed. The Kagawa Nutrition University Publishing Division documented the mean refuse rates for Japanese cooking standards (Kagawa, 2016). The list indicates the refuse for each type of fruit and vegetable. The latest data was retrieved from the 7th edition of the Tables of Food Composition (2016) in Japanese. Next, the refuse for each product was subtracted from the harvest in each grid cell.

The population in each grid cell was available from the land use section of TMG (2016a). The self-sufficiency (η) for grid cell (l) was obtained as follows,

$$\eta_l = \frac{\sum_i H^{i,l}(1 - r^i)}{C^l} \tag{2}$$

where:

$H^{i,l}$ is derived from equation (1) [kg]

r^i is the refusal rate or non-edible percentage per vegetable (i) [-]

C^l is the reference consumption of fruit and vegetables for population in grid cell (l) [kg]

2.2.6. Step 5: Nutritional self-sufficiency

The nutritional self-sufficiency was estimated in each grid cell utilizing the production results from Step Three. The total nutrient content in each grid cell for each fruit and vegetable species was estimated with data provided by The Kagawa Nutrition University Publishing Division (Kagawa, 2016). The dataset provided the mean nutrient content according to fruit and vegetable in Japan. The Ministry of Health, Labour and Welfare (MHLW) conducts a yearly survey of the food sources of dietary nutrients in Japan

(MHLW, 2015). A selection of nutrients that provide more than 50% from fruits and vegetables was made and retrieved from the 2015 results for the present study. The nutritional self-sufficiency (η) for grid cell (l) of nutrient (n) was obtained as follows,

$$\eta_{l,n} = \frac{\sum_i H^{i,l}(1 - r^i)N^{i,l,n}}{C^{l,n}} \quad (3)$$

where:

$H^{i,l}$ is derived from equation (1) [kg]

r^i is the refusal rate or non-edible percentage per fruit or vegetable (i) [-]

$N^{i,l,n}$ is the content of nutrient (n) in vegetable (i) in grid cell (l) [kg]

$C^{l,n}$ is the reference consumption of each nutrient for the population in grid cell (l) [kg]

Finally, for each dominant urban or open land use pattern, a representative grid cell was selected and their corresponding results from each step listed for an in-depth discussion on a neighborhood scale.

2.3. Results

2.3.1. Identified farmlands

Vegetable fields, orchards, allotments, and experience UA lands were identified and documented according to their current and potential use in Tokyo (Table 3). The total of the current productive UA land is 54,862,092 m^2. An increase of 45% to 79,635,198 m^2 potential UA land surfaces could be achieved when including stable vacant lots. Despite the lack of current UA production in many municipalities, the shortage can potentially be eliminated with stable vacant lands as shown in Figure 7.

Table 3. Current and potential identified land uses in Tokyo for UA.

Scenario		Land use type	Mean size per plot [m^2]	Plots [n]	Area [m^2]
Current (Figure 1)	Professional	Vegetable field	571	34,607	39,455,099
		Orchard	616	14,166	14,749,526
	Hobby	Allotment	1,115	415	496,172
		Experience	1,949	75	161,295
Potential (Figure 2)		Stable vacant land	153	29,508	24,773,106
		Total		78,771	79,847,006

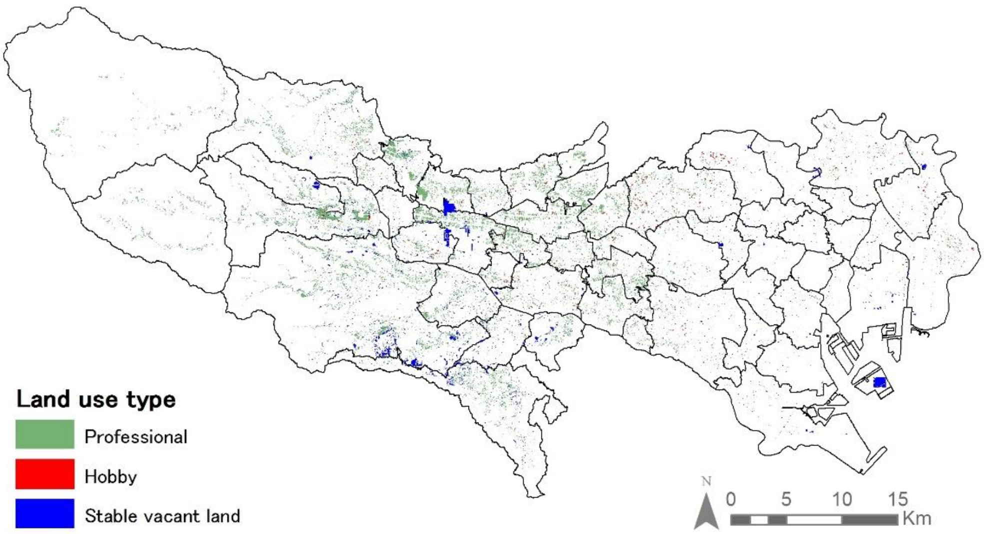


Figure 7. Identification of current and potential UA land uses in Tokyo. Data source base map: Administrative map of Tokyo's municipalities and land use data (TMG, 2016a).

2.3.2. Categorization of Land use patterns

A total of 1,479 individual grid cells are shown in Figure 8. The eastern part of Tokyo (= Tokyo 23 special wards), which is mostly urban, shows two main variations in land uses. Type A, which is in the center core of the city and Type B, a belt of urban area mixed with farmlands (mosaic of land uses) surrounding the core of the city. These areas were mostly developed during the rapid population growth of the city and did not follow strict planning codes and have been described as Japanese sprawl. Despite of the mixture in land uses, Type B has some of the highest population density in Tokyo. The open spaces in this area are found to be public parks (e.g. Shibuya Park) and fields along the rivers (e.g. Arakawa River and Sumida River) belonging to Type C and Type D. Other areas towards the northwest of central Tokyo (= north Tama area) also contain a large number of parks (e.g. Showa Kinen Park) that are represented in the grid cells. These areas still contain a high population density but simultaneously have a great number of farmlands (Figure 7). The southwest of Tokyo (= south Tama area) has areas that are similar to the urban core of east Tokyo but still contains a great number of open spaces. This is because the area had been designated for the development of Tama New Town to meet the housing demand during the rapid expansion of the city in the sixties. Tama New Town is developed according to strict design concepts with condominiums and open spaces. The western part of Tokyo (= west Tama area) is mostly Type E and F because of the hilly typography with very low population density in forest area. The farmland that is present in these areas can mostly be considered as rural agriculture.

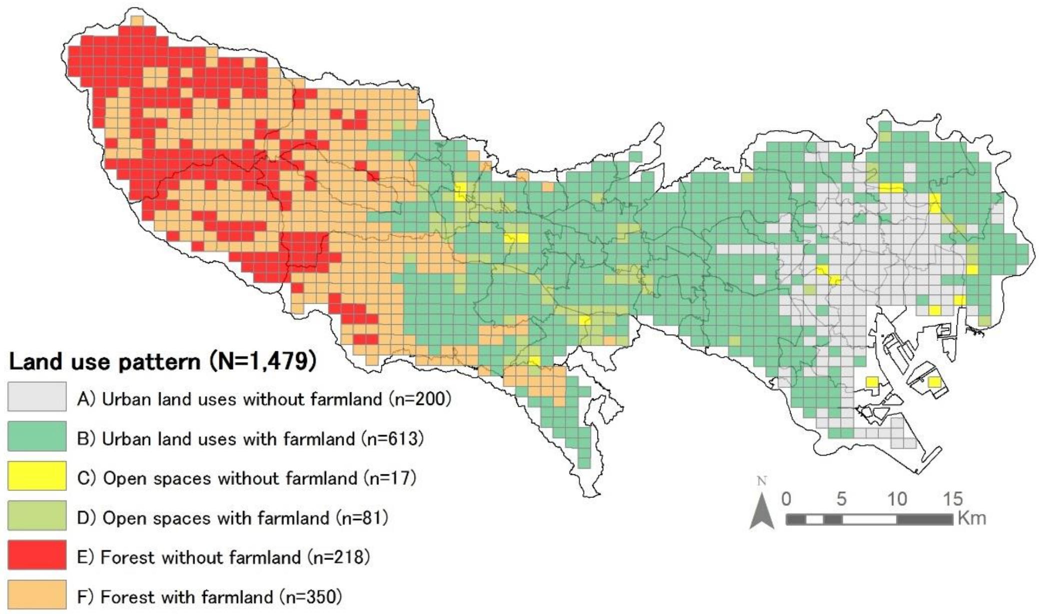


Figure 8. Land use classification with 1 km^2 grid structure of Tokyo. Data source base map: Administrative map of Tokyo's municipalities and land use data (TMG, 2016a).

2.3.3. Reference consumption and production

The reference consumption [kg] shows a total demand of 1,521,809,100 kg from fruits and vegetables in Tokyo (Figure 9). The grid cell analysis show that the demand for fruit and vegetables is concentrated in land use patterns A and B, which is the dominantly urban representing the cities inner core and surrounding suburban area.

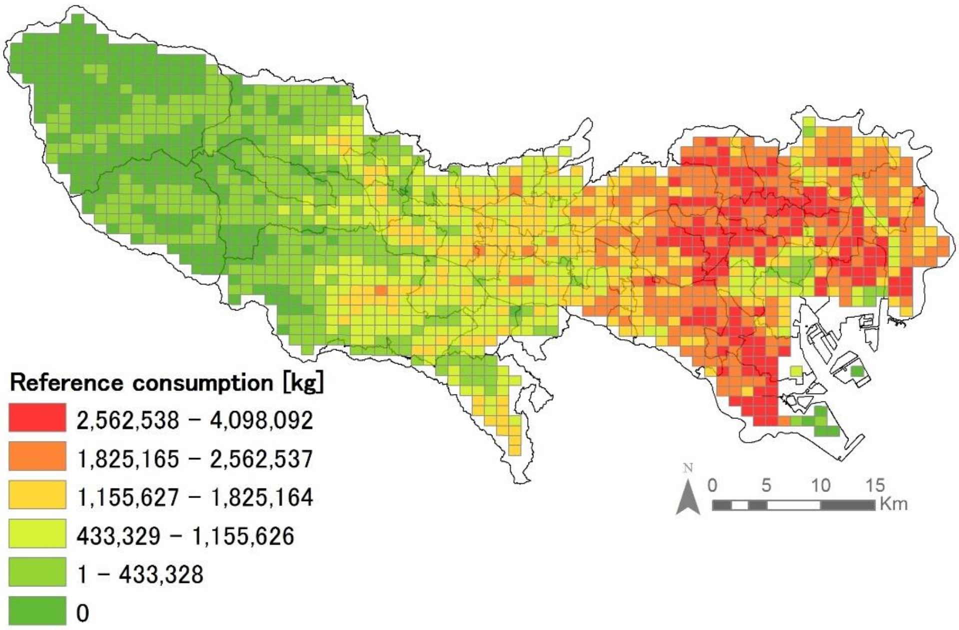


Figure 9. Consumption of fruit and vegetables within each 1x1 km grid cell of Tokyo. Data source base map: Administrative map of Tokyo's municipalities and land use data (TMG, 2016a).

The production [kg] of fruit and vegetables in Tokyo is distributed over different areas as shown in Figure 3. There is an annual production of 71,560,533 kg from professional UA and 3,472,208 kg from hobby UA. The grid cells that were categorized as Type B, D, E and G in Figure 10 showed the highest production by grid cell. However, because of the cultivation and combinations of different fruits and vegetables, there are differences in the production by grid cell depending on the type and species grown in the municipality it is located in.

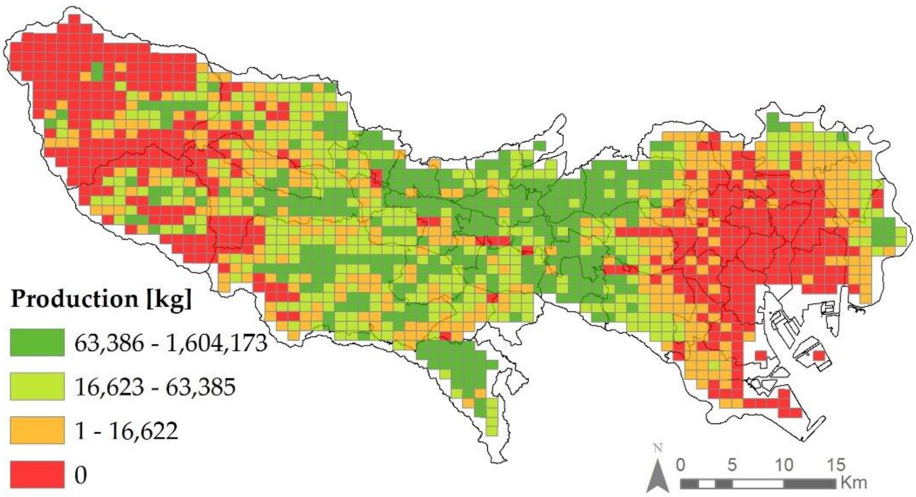


Figure 10. Current fruit and vegetable production within each 1 km^2 grid cell of Tokyo. Data source base map: Administrative map of Tokyo's municipalities and land use data (TMG, 2016a).

The potential production from stable vacant lands shows a considerable increase of 126,884,116 kg in production in addition to the current production (Figure 9). Furthermore, the grid cells identified as Type A, which includes many vacant lands show some potential compared to the result of the current situation (Figure 11).

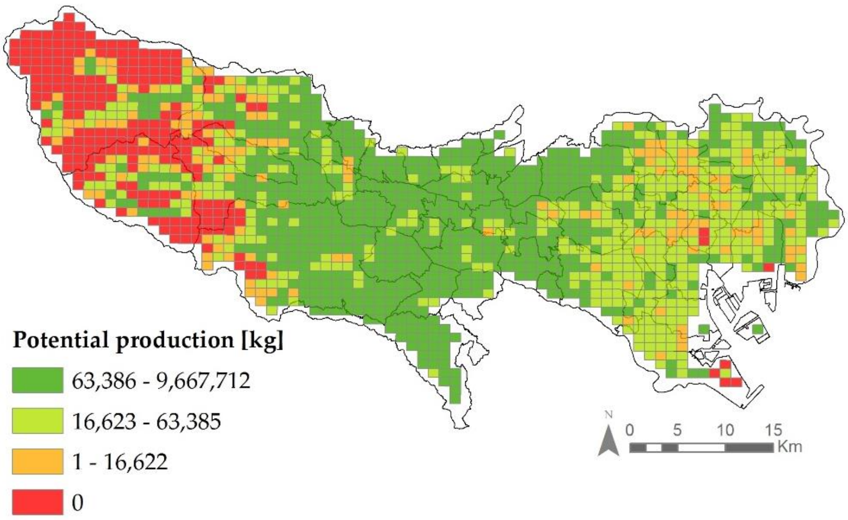


Figure 11. Potential fruit and vegetable production within each 1 km^2 grid cell of Tokyo. Data source base map: Administrative map of Tokyo's municipalities and land use data (TMG, 2016a).

The self-sufficiency in Tokyo followed similar trends as the results in Figure 3 and 4. The total population covered in the grid cells was 11,912,400 people, of which 5,889,811 male and 6,022,589 female. The current self-sufficiency estimated for the entire city region was 4.27% and the potential self-sufficiency was 11.73%. It was found that the median self-sufficiency was zero in Type A, Type C and Type F of the current production scenario. The mean self-sufficiency is the lowest in Type B (3%), higher in Type D (6%), Type G (105%), and the highest in Type E (224%) as shown in Figure 12 and detailed in Table 4.

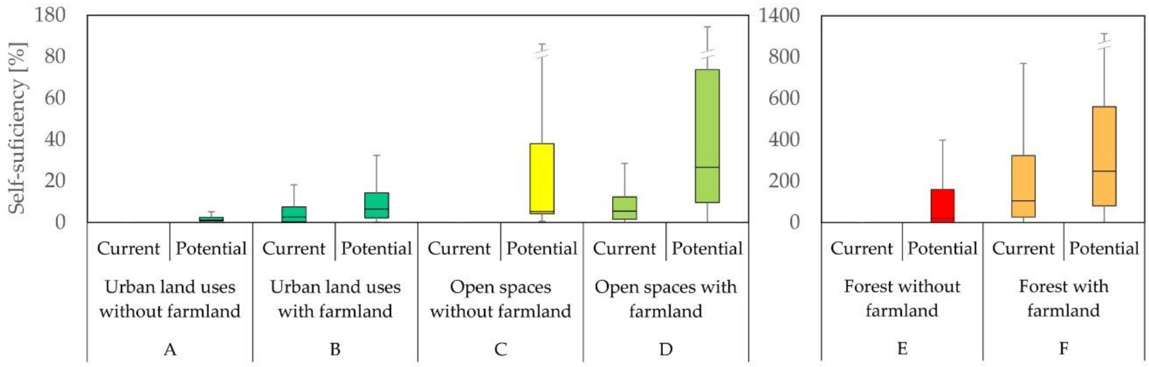


Figure 12. Box-plot of current and potential fruit and vegetable self-sufficiency within each land use pattern in Tokyo.

Table 4. Self-sufficiency according to land use categorization.

	Factor	A	B	C	D	E	F
Current	Min	0	0	0	0	0	0
	Q1	0	0	0	2	0	27
	Median	0	3	0	6	0	105
	Q3	0	8	0	12	0	324
	Max	0	599	0	298	0	12,739
	IQR	0	7	0	11	0	297
	Upper Outliers	1	51	0	9	0	32
	Lower Outliers	0	0	0	0	0	0
Potential	Min	0	0	1	0	0	1
	Q1	1	2	4	10	0	82
	Median	1	7	5	27	20	249
	Q3	2	15	38	74	160	561
	Max	27,132	764	8,522	1,120	651	13,775
	IQR	2	12	34	64	160	479
	Upper Outliers	20	59	3	11	1	32

For the current production scenario (Figure 13) focusing on UA, Type B and type C were selected because of its dominant urban land uses. These are mostly located inside the 23 special wards of Tokyo (and suburban areas surrounding the inner core) as well as the populated areas of the Tama region. The areas surrounding the urban core had, despite having a high population density, a considerable presence of UA, which contributed to the self-sufficiency of the area. Similar trends were found in areas with the same type of land uses. A total of 4.22% fruit and vegetable self-sufficiency was found in the urban areas of Tokyo of which hobby UA contributed 0.20%.

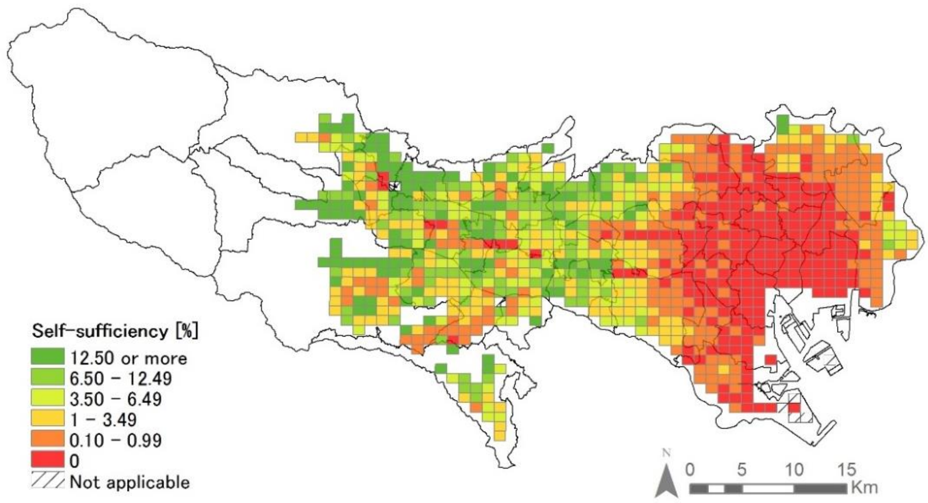


Figure 13. Current fruit and vegetable self-sufficiency within each 1 km^2 grid cell of Tokyo from Type's A, B, C and D. Data source base map: Administrative map of Tokyo's municipalities and land use data [36].

For the potential self-sufficiency scenario (Figure 14), focusing on UA, Type A was added to the selection of Figure 13 because of its dominant urban land uses. Both Type A and Type B contain stable vacant lots that are contributing to the self-sufficiency in the grid cell. The total potential self-sufficiency in urban areas was found to be 11.68% of which stable vacant lands contributed 7.45%.

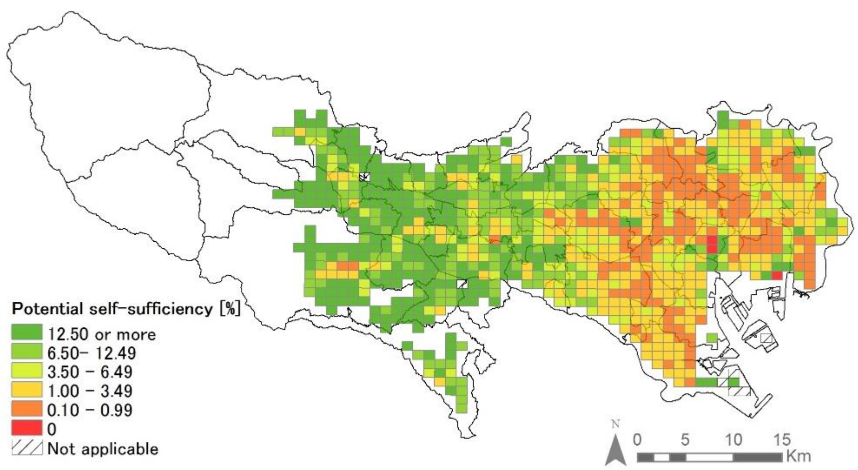


Figure 14. Potential fruit and vegetable self-sufficiency within 1 km^2 grid cell of Tokyo from Type's A, B, C and D. Data source base map: Administrative map of Tokyo's municipalities and land use data (TMG, 2016a).

2.3.4. Nutritional self-sufficiency

Vitamin A, vitamin K, and vitamin C were selected in the present chapter (Figure 15 and Figure 16) because of their intrinsic need from fruits and vegetables in the Japanese diet (MHLW, 2015).

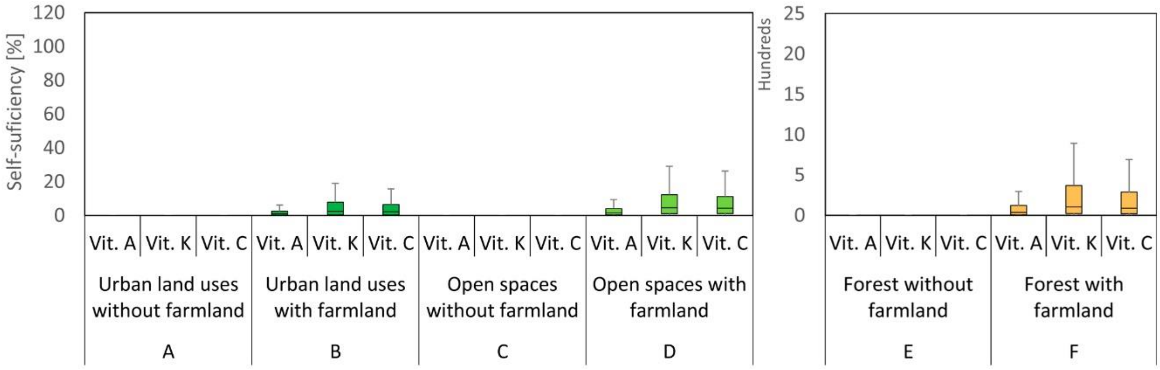


Figure 15. Box-plot of current fruit and vegetable nutritional self-sufficiency within each land use category in Tokyo.

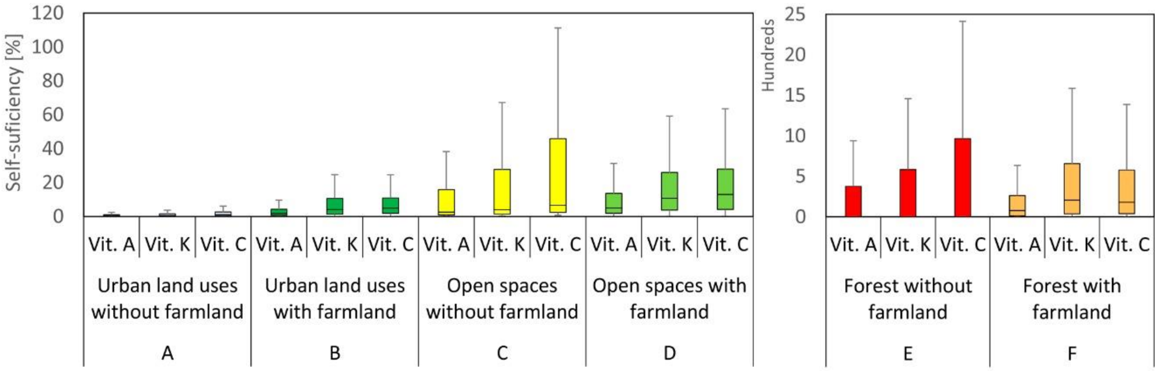


Figure 16. Box-plot of potential fruit and vegetable nutritional self-sufficiency within each land use category in Tokyo.

The spatial distribution of the nutritional self-sufficiency of each selected nutrient per grid cell has similar patterns as the self-sufficiency Figure 6 and Figure 7. Overall, vitamin K has the highest self-sufficiency followed by vitamin C and vitamin A (Table 5). Depending on the land use pattern, vitamin K contains higher rates in the current scenario; however, vitamin C has higher rates in the potential scenario because of variations in vegetables in hobby UA.

Table 5. Nutritional self-sufficiency according to land use categorization.

		Nutritional self-sufficiency [%]								
		Urban land uses without farmland (A)			Urban land uses with farmland (B)			Open spaces without farmland (C)		
		Vitamin			Vitamin			Vitamin		
	Factor	**A**	**K**	**C**	**A**	**K**	**C**	**A**	**K**	**C**
Current	Min	0	0	0	0	0	0	0	0	0
	Q1	0	0	0	0	0	0	0	0	0
	Median	0	0	0	1	3	2	0	0	0
	Q3	0	0	0	3	8	7	0	0	0
	Max	0	0	0	308	861	525	0	0	0
	IQR	0	0	0	2	7	6	0	0	0
	Upper*	0	0	0	67	66	48	0	0	0
	Lower*	0	0	0	0	0	0	0	0	0
Potential	Min	0	0	0	0	0	0	0	0	1
	Q1	0	0	0	1	1	2	1	1	2
	Median	0	1	1	2	4	5	3	4	7
	Q3	1	2	3	4	11	11	16	28	46
	Max	19.58	34.23	56.62	311	866	533	104	162	269
	IQR	1	1	2	4	9	9	15	26	44
	Upper*	31	31	31	67	70	61	3	3	3
	Lower*	0	0	0	0	0	0	0	0	0
		Open spaces with farmland (D)			**Forest without farmland (E)**			**Forest without farmland (F)**		
		Vitamin			**Vitamin**			**Vitamin**		
	Factor	**A**	**K**	**C**	**A**	**K**	**C**	**A**	**K**	**C**
Current	Min	0	0	0	0	0	0	0	0	0
	Q1	0	1	1	0	0	0	8	22	20
	Median	2	5	4	0	0	0	36	105	87
	Q3	4	12	11	0	0	0	123	370	289
	Max	110	322	245	0	0	0	13.26	56.89	16.48
	IQR	4	11	10	0	0	0	116	348	268
	Upper*	12	11	9	0	0	0	31	37	30
	Lower*	0	0	0	0	0	0	0	0	0
Potential	Min	0	0	0	0	0	0	0	0	0
	Q1	2	4	4	0	0	0	13	36	38
	Median	5	11	13	0	0	0	77	207	179
	Q3	14	26	28	376	583	965	262	656	578
	Max	351	649	878	6.62	10.55	17.44	22.19	56.89	50.11
	IQR	12	22	24	376	583	965	248	620	539
	Upper*	9	9	9	2	2	2	37	34	38
	Lower*	0	0	0	0	0	0	0	0	0

* Outliers

2.3.5. Representative grid cells per type of land use pattern

For each land use pattern two representative grid cells were selected (Fig. 17) to analyze the details and characteristics of the land use patterns.

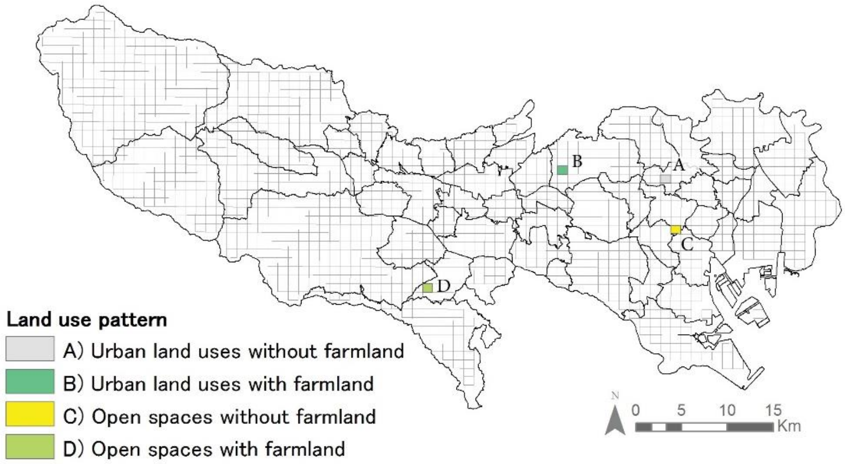


Figure 17. Selection of representative grid cells for each urban land use category of Tokyo. Data source base map: Administrative map of Tokyo's municipalities and land use data (TMG, 2016a).

The randomly selected representative grid cells provide visual land uses details (Figure 18). Furthermore, population according to gender, fruit and vegetable production, fruit and vegetable self-sufficiency, and nutritional self-sufficiency of selected nutrients (Table 5). The results show the trends in population density and relationship with the categorization of land use patterns as well as the corresponding gradation and mixture in land uses. Especially the potential self-sufficiency scenario, which was designed with stable vacant lands, shows potential to increase the resilience and DRR of the population. In addition, the maps of each selected grid cell show the gradation in land uses from category A to D.

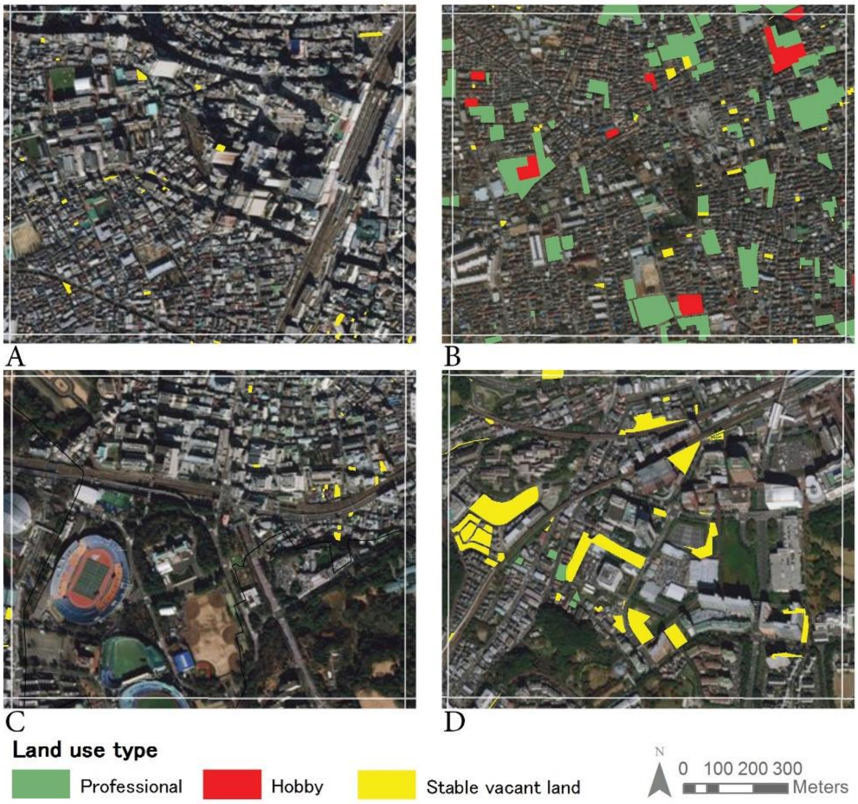


Figure 18. Selection of grid cells for each urban land use category of Tokyo. Data source base map: Administrative map of Tokyo's municipalities and land use data (ESRI, 2017; TMG, 2016a).

Table 6. In-depth results categorized according to each selected grid cell.

		Population [n]		Professional production [kg]		Hobby production [kg]		Current self-sufficiency [%]				Potential self-sufficiency [%]			
Code	**Municipality**	**Male**	**Female**	**Vegetable**	**Fruit**	**All.**	**Exp.**	**Products**	**vit. A**	**vit. K**	**vit. C**	**Products**	**vit. A**	**vit. K**	**vit. C**
A	Toshima-ku	7,792	7,207	0	0	0	0	0	0	0	0	1.16	81.44	1.27	2.10
B	Nerima-ku	7,694	7,935	188,431.9	7,216.99	18,533.84	89,166.25	13.29	5.15	14.50	9.01	14.68	7.38	18.97	14.79
C	Shinjuku-ku	2,091	2,641	0	0	0	0	0	0	0	0	2.39	1.06	1.63	2.70
D	Tama-shi	4,679	4,724	1,817.04	28.74	0	0	0.13	0.02	0.08	0.12	24.30	5.28	8.25	13.63

2.4. Discussion

2.4.1. Land use patterns

In the present case study, UA practices were found to have a profound impact on the self-sufficiency of communities in each grid cell. In particular, the two land use types that contain a mixture of urban and open spaces with farmlands (Type's B and D) showed high rates of self-sufficiency. These two types contained a mosaic of urban or open spaces with farmlands. The roles of UA in each land use pattern remain the same; however, their contributions differ based on the types, locations, and areas – influencing the resilience. Other land use patterns (Type A) have little or no self-sufficiency in the present scenario. Stable vacant lands impacted core urban areas (Type's A and B), open spaces (Type's C and D), and the forestry areas (Type's E and F).

Different models of urban growth within the different areas of Tokyo are represented in the urban land use pattern. Areas exhibiting organic urban growth (Japanese sprawl) contained more vacant lands (Sorensen, 2000). Regions that were formally developed according to modernistic planning concepts (Mumford, 2002), showed less presence of both vacant lands and UA. Thus these areas contained less possibility for transformation into UA without compromising other land uses. The reason or this is that UA land uses were considered to be rural land uses, these planned regions only exceptionally contained UA lands. For example, Tama New Town (Ducom, 2008) in Type C was planned according to high population densities as a response to demand for more housing in the city region of Tokyo. The purpose of the new town was therefore fulfilled. During the planning stage, earthquake exposure was taken into consideration, resulting in wider roads and plenty of open spaces in the forms of parks surrounding the condominiums.

Land use patterns dominated by forestry land uses (Type E and F) showed diverse results. Some grid cells were unoccupied, which made it impossible to conduct a self-sufficiency study. Having excluded these grid cells, remaining areas could be categorized further into regions with low population densities and high self-sufficiency, and regions with low population densities and low self-sufficiency. The reason is because there were no agricultural activities found that met the criteria of this study. In reality, although emergency responses may take long, households located in these areas often maintain homestead gardens as a potential source of additional emergency food. In addition, wildlife, and wild plants (e.g. mushrooms (Sadler, 2003) or nuts (Ros, 2010)) in the forests of these areas can help provide the populations with nutrients until the normal distribution processes are recovered.

Tokyo experienced a transit oriented development in the 1920's by private railway companies for the purpose of modernization of the country (Okata & Murayama, 2011). These commercial developments on large land areas were combined with the development of housing estates to pay for the railway construction. High density areas that were planned formally alongside the railways left little space for UA, influencing the self-sufficiency as shown in Figure 19. Areas further removed from the stations that were not formally developed experienced scattered sprawl (creating a mixture between urban and agricultural land uses) because of the rapid growth of the city in the sixties and the lack of formal planning policies. These areas are still the most vulnerable today and were often built up with low quality housing (e.g. wooden rental houses - Moku-chin in Japanese), lacked infrastructure, and have narrow roads (A Sorensen, 2000). Local municipalities (e.g. Nerima ward) have been exploring the potential to utilize the remaining UA in these areas for low-cost disaster preparedness purposes (evacuation and food provisioning) (Sioen et al., 2017).

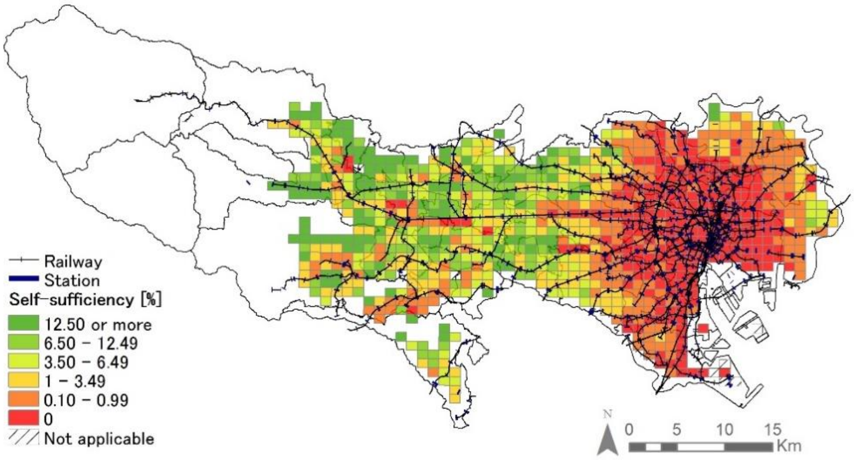


Figure 19. Selection of representative grid cells for each urban land use category of Tokyo. Data source base map: Administrative map of Tokyo's municipalities and land use data (TMG, 2016a).

TMG (2013) created an aggregated risk assessment of Tokyo as means to inform its residents and to implement policies to protect the lives and assets from earthquake damages. The assessment is conducted by aggregate the risks of: a) collapsing of buildings, b) spread of fire, c) the combination of building collapse and spread of fire, and d) difficulty for emergency responses. The data is collected on Cho Cho Moku level boundaries, which is the smallest unit of spatial analysis in Japan. As shown in Figure 20, the greatest aggregated risk is found in the suburban area surrounding the inner core of the city. This is distributed around Ring Road No. 7, which represents the areas from Shitamachi to Yamanote (TMG, 2013). The surrounding suburban area is similar to the areas discussed above where Moku-chin buildings were constructed with the lack urban planning policies, which means that there is a lack of infrastructure that can help prevent the spread of fire (e.g. wide open roads).

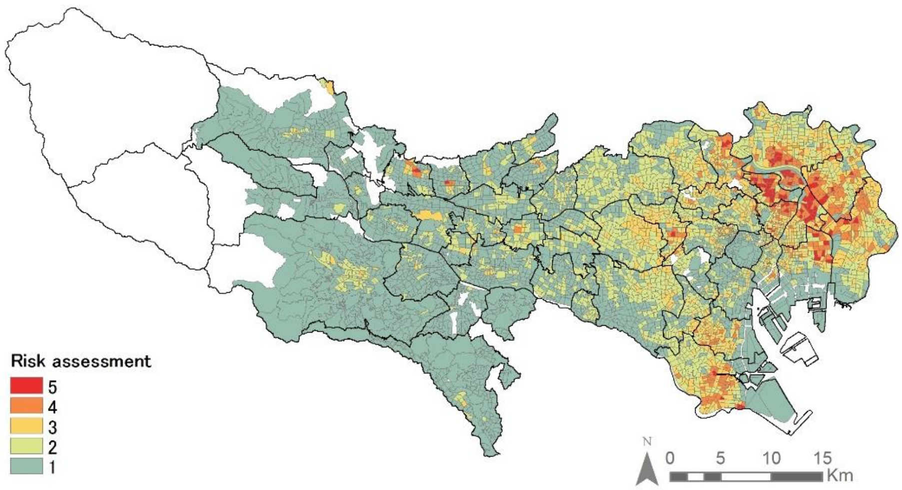


Figure 20. Aggregated risk assessment of Tokyo. Some risk = 1 and high risk = 5. Data source base map: Administrative map of Tokyo's municipalities (TMG, 2016a), adapted and modified from (TMG, 2013).

2.4.2. Strategies to increase self-sufficiency

Olsson et al. (2016) discussed the need to re-couple urban and rural regions food production from a resilience point of view (Olsson et al., 2016). The European case studies all experienced a reduction in agricultural land uses over recent years within the city region, consequently reducing regional food availability. Local municipalities reacted to the loss of these lands by organizing a "food council". However, they concluded that without the implementation of binding policies the agricultural lands will continue to decline (Olsson et al., 2016). The present case study of Tokyo faces similar challenges. UA land uses declining under the current policies and there are expectations that this trend will increase in the future, with a negative impact on the presence of greenery in the city (Yokohari & Amati, 2005) and self-sufficiency as shown in the present case study.

Viljoen and Bohn (2009) discussed the essential infrastructure of UA and reflected on the role UA has as "ornament" in a compact city (Andre Viljoen & Bohn, 2009). However, the study also proposes that UA should be a long-term urban land use. The same authors suggested productive urban landscapes in the form of UA (A Viljoen, Bohn, & Howe, 2005). The study includes design implementations and discusses opportunities for adoption in-between existing urban land uses for the improvement of general urban sustainability (Andre Viljoen & Howe, 2012). Such design implementations can be adopted in a city which contains a high population density such as Tokyo. Type A, which currently contains no UA and functions as the urban core of Tokyo, can adopt such strategies to increase its self-sufficiency rates and corresponding resilience in event of large earthquakes by allocated stable vacant lands as hobby farms. In addition, Tokyo fits the description by Viljoen and Howe (2012) about long-term presence of UA land uses in a variety of forms, offering different functions such as food and agriculture experiences for urban residents.

International discussions have been held among city mayors to adapt and promote UA practices (UN-Habitat & ESCAP, 2015). These UA activities secure food on a local scale and create greener cities in the Asia and Pacific region. In addition, research on nutrition-sensitive agriculture has been increasing in importance. In particular, urban areas typically foster a busier lifestyle compared to that in rural areas, and consequently can benefit greatly from the presence of UA activities (Gerster-Bentaya, 2013). This presence leads to healthier environments and lifestyles which can be seen by the increasing importance placed on integrating health aspects in urban planning (Rydin et al., 2012).

Participation in UA activities can also be linked with other crucial activities in Japan. A study conducted among high school children concluded that experiencing an earthquake alone did not increase awareness, instead, active learning steps had to be taken to develop a lasting effect and thus be better prepared (Shaw et al., 2004). By utilizing UA as a platform for disaster awareness in the present case study, participants learned about farming processes while improving their diets with fresh fruits and vegetables. They can then also familiarize themselves with farmers and other residents, and increase their knowledge about evacuation spaces in the neighborhood.

2.4.3. Limitations, applicability, and future work

The present study has several limitations. The nutritional self-sufficiency results are considered to be an underestimation because the harvests from professional UA production can only be quantified by what is sold to the market. Self-consumption and direct sales are not documented in these results. In addition, previous studies reported that non-market based food sharing is common practice in Japan (Kamiyama et al., 2016). The production from hobby UA is considered to be an overestimation; only one study in Japan has been found on the production from hobby UA, and this study was conducted among pioneering hobby UA farms, which might have been ideal case scenarios. In addition, nutrient contents in fruits and vegetables also vary per season, by year, and according to weather conditions. However, because there was insufficient data available for all the products used in the present study, standard values from the data source were utilized.

The present study has applicability to other cities with similar land uses around the world. For example, Jakarta Metropolitan Area, contains a great number of UA land uses. These regions with mixed land uses have been widely described in literature as Desakota regions (McGee, 1991). Furthermore, other cities in Asia and the Pacific are not strictly divided between urban and rural areas. Rather, the development of both urban and rural areas are interrelated (UN-Habitat & ESCAP, 2015).

Future research should seek deeper understanding of the potential of different land uses in the urban area of Tokyo, and identify additional land uses that are suitable for transformation into agricultural uses. The transformation might be different in each context, therefore, a comparative study would identify opportunities and challenges. Lastly, the social willingness and economic impacts of the transformation should be estimated.

3. NUTRITIONAL SELF-SUFFICIENCY ACROSS TIME IN NERIMA WARD

3.1. Introduction

Rations and emergency foods in post-disaster situations are rich in carbohydrates and focus on providing energy to survivors (WHO, 2004). Such foods conventionally have a long shelf life (non-perishable). Nutrient-rich and fresh products, however, have short shelf lives (Nakazawa & Beppu, 2012). Non-perishable foods have been preferred for emergency responses and meet the short-term needs of survivors. Although they were intended for short-term interventions of a few days, post-earthquake studies from around the world - including Haiti (Bassett, 2010), Indonesia (Centers for Disease Control and Prevention, 2006), Japan (Tsuboyama-Kasaoka & Purba, 2014), and Nepal (UNICEF, 2015) (Fig. 21) - have reported that survivors continued to rely on emergency food during mid- (days to weeks) to long-term (weeks to months) periods, depending on the area and scale of the disaster (Nakazawa & Beppu, 2012) and encountered dietary related health issues.

Figure 21. Reported effects of dietary related health issues in post-disaster studies. Base map adopted and modified from Sundermann et al., 2014.

For example, after the Great East Japan Earthquake on March 11th, 2011, distribution of fresh vegetables, meat, fish, and dairy products with well-balanced proteins and vitamins (Tsuboyama-Kasaoka & Purba, 2014) was difficult (Inoue et al., 2014; Nakazawa & Beppu, 2012; Nozue et al., 2014; Tsuboyama-Kasaoka et al., 2014). Even one month later, survivors' diets were largely limited to long-shelf life food, which had a high percentage of carbohydrates (Inoue et al., 2014; Tsuboyama-Kasaoka & Purba, 2014). In some areas, disasters prior to the earthquake already had diminished rations, exacerbating the lack of nutrients. To make matters worse, the earthquake damaged the main industrial nutrition supplement provider (Amagai et al., 2014). Below is a conceptual representation of the available food stock and external relief based on the data documented by The Science & Technology Foresight Center, 2012 and shown in Figure 22.

Figure 22. Conceptual representation of the different stages of food availability and supply in the aftermath of a large earthquake adapted and modified from The Science & Technology Foresight Center, 2012.

The lack of fresh fruits and vegetables resulted in deficiencies of corresponding nutrients such as dietary fiber and vitamin C. A survey of those in temporary shelters in Ishinomaki, Japan linked a lack of dietary fibers normally found in fresh fruits and vegetables, with an increased number of gastrointestinal symptoms (Inoue et al., 2014). These symptoms may have also contributed to decreased food intakes among 23% of the 236 survivors surveyed one month after the disaster (Inoue et al., 2014). Diets rich in carbohydrates also caused high blood glucose levels (Inoue et al., 2014). Research conducted 15 weeks after the Great East Japan Earthquake found that cardiovascular diseases had increased significantly (Aoki et al., 2013). Vitamin C is known to prevent cardiovascular diseases (Padayatty et al., 2003), but was lacking at the time in previously healthy people (Amagai et al., 2014). The lack of proper nutrition over prolonged periods can thus result in various health issues (Slavin & Lloyd, 2012). Similar situations can occur in Tokyo, where rations consist of crackers, pregelatinized rice, instant noodles, and rice (Nakazawa & Beppu, 2012). Although Japan is prone to large-scale disasters, one household survey revealed that most households did not store rations or did so insufficiently (Nakazawa & Beppu, 2012). As access to nutrients during disaster situations has proven to be challenging, alternative nutrient sources must be explored and better understood.

In this chapter, it is examined how urban agriculture (UA) can function as one possible disaster preparation food source to supplement heretofore the emergency foods. Disaster preparation food (Nakazawa & Beppu, 2012) is defined as: "*food needed to maintain psychological and physical health for disaster survivors between the time a disaster occurs and when life returns to normal*" (Nakazawa & Beppu, 2012) (p. 46). According to this definition, disaster preparation food includes food with a short-shelf life that can be used until distribution of ingredients is restored (Nakazawa & Beppu, 2012). Furthermore, an assessment of pre-earthquake investment after the 2010 earthquake in Haiti identified UA as a source of local food security and nutrition (Fao, 2011). UA is defined as the growing of plants and raising of animals inside the city (Drescher, 2001; Mougoet, 2000). People engaged with UA have reported positive impacts on psychological health, nutrition (K. H. Brown & Jameton, 2000; Rydin et al., 2012; Wilkins et al., 2015), and community resilience (Wesener, 2015). Although more research is required, a systematic literature review showed positive associations with dietary diversity (Warren, Hawkesworth, & Knai, 2015b). Therefore, it was hypothesized that UA may very well be a viable disaster preparation food source if available in disaster struck areas.

Previous UA self-sufficiency studies addressed annual self-sufficiency (Grewal & Grewal, 2011; Omari, 1986; Rodríguez-Rodríguez et al., 2015; Sioen et al., 2016a). However, disasters are intractable and impact at random (Altay & Green, 2006). Therefore, the present chapter aims to quantify UA vegetable production and nutritional self-sufficiency throughout the year for mitigating post-disaster situations.

3.2. Materials and methods

The year-round production of vegetables was estimated by assuming constant level of production across vegetable harvest periods. Next, the weight of each harvest was converted into nutrients and their total availability calculated. A reference consumption of each nutrient was estimated by multiplying dietary reference intakes with population statistics. Finally, self-sufficiency throughout the year was quantified by dividing the available nutrients from UA with the reference consumption of the population, as detailed in Fig. 23.

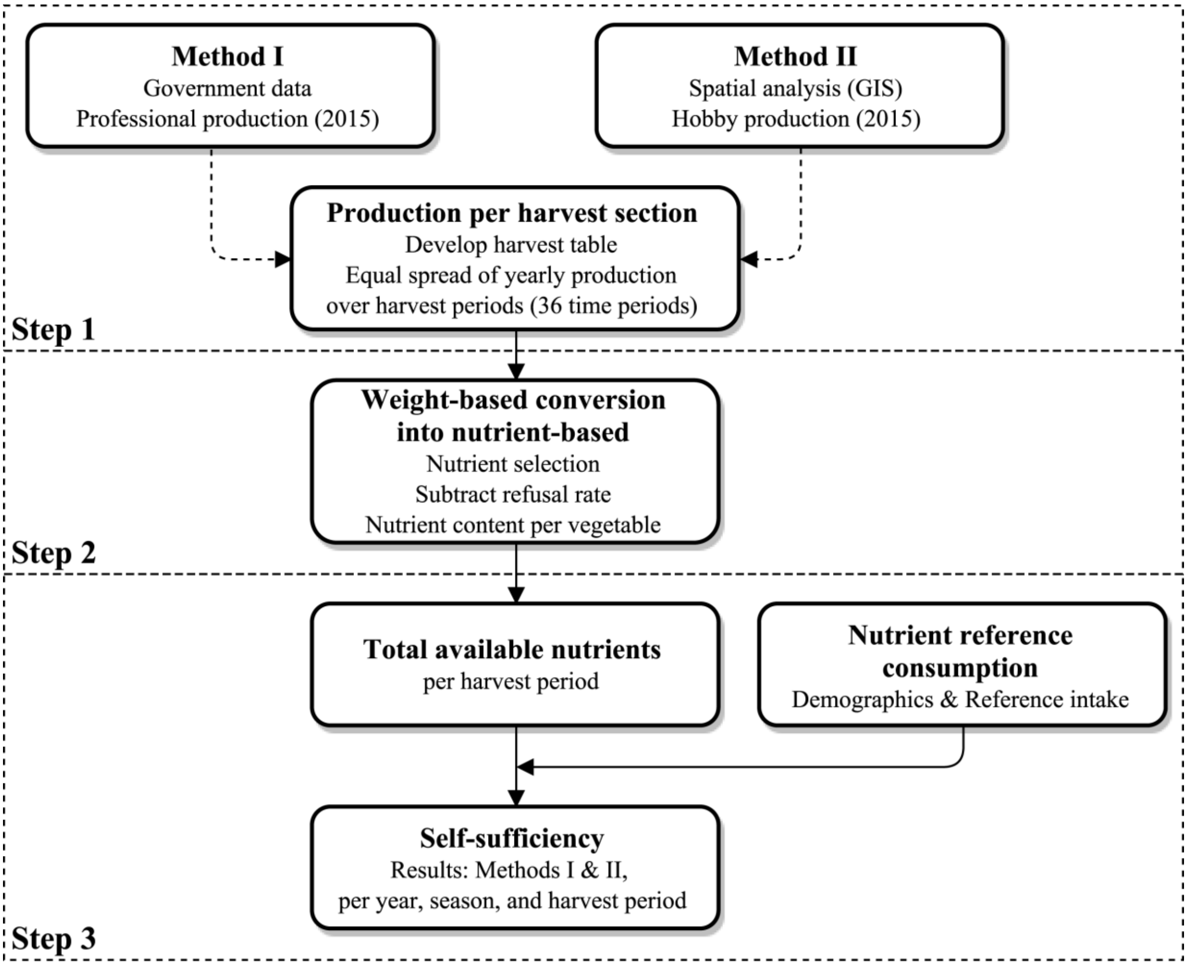


Figure 23. Flowchart of analysis.

3.2.1. Step 1: Production of vegetables throughout the year

Disasters can occur at any given time of year (Altay & Green, 2006). Therefore, as a disaster preparedness study, it was decided that the available harvest in anticipation of such occurrences at any given time of year was a critical factor. In the selected case study, three types of full-soil UA were identified (Tahara et al., 2011; Sioen et al., 2016): (1) Professional UA, which is similar to its rural counterparts but located within the city boundary; (2) Experience UA, that is farmed by hobby users but owned by professionals. The professionals provide planting plans and practical advice to optimize the yields of the hobby farmers; and (3) Allotment UA, that is maintained by hobby farmers and often have a high variety in crops (MacNair, 2002; B. M. Shiraishi, 2001; Sioen et al., 2016a; Tahara et al., 2011). A Japanese municipal survey supplied data on the production of professional UA. However, data on the production of hobby UA was unavailable. Therefore, two methods were developed to estimate the total production of vegetables in the study site. Method I uses the aforementioned government survey data; Method II analyzes land use data from a Geographic Information System.

3.2.1.1. Method I

Data from the 2015 Tokyo Metropolitan Agricultural Products Production Survey (TMG, 2015b) was utilized. This survey on professional UA is conducted every 5 years by the Tokyo Metropolitan Government and lists the annual production and area by vegetable type.

3.2.1.2. Method II

Information on allotment and experience UA (Sioen et al., 2016a; Tahara et al., 2011) was collected and processed in a Geographic Information System (GIS) (ArcGIS ver. 10.3). High-tech indoor and rooftop farms were excluded because they are susceptible to earthquakes. Through field observations and interviews with the UA section of the municipality, and with local professional and hobby farmers (2015 - 2016), it was found that both experience and allotment farms were present in the case study. Each type has their own visual characteristics. Because the plots located on experience farms are grown by hobby farmers under the strict guidance of a professional farmer, all the plots have similar crop patterns and choices of crops. Therefore, the fields are visually similar to each other. Allotment farms are also grown by hobby farmers; however, because some of these farmers have no knowledge on agricultural activities and they are not receiving guidance by a professional farmer, these plots have a more disordered appearance due to the high diversity of crop combinations in the different plots (Sioen et al., 2016a; Tahara et al., 2011).

Hobby UA areas were identified according to the three steps developed by Sioen et al. (2016) as follows: 1) access to the municipality database (Nerima ward, 2016a, 2016b) to retrieve the location of each hobby farm according to type (experience or allotment); 2) confirmation and documentation of their locations and a systematic scan of the entire ward with Google Earth Pro (ver. 7.1.8) to identify remaining undocumented farms; and 3) ground confirmation with Google Street View. The analysis was updated according to 2016 study site satellite imagery (Sioen et al., 2016a). To reduce the margin of error of the identification through satellite imagery, typical examples of each type of the documented farms were randomly selected and visited on site for confirmation of the type and its location (Jul. 2016). An additional accuracy assessment was conducted with the help of land use data in GIS from TMG (2016a), indicating the individual plot sizes of all land uses. The documented locations and sizes from the present study were fitted according to the plots from the land use map.

The total area of each type of farmland was multiplied with an average production indicator. This indicator shows the average production (vegetables [kg] in a square meter) from previously reported samples (for each type 5 plots were analyzed over a one year time frame) (Table 7).

Table 7. Production by farmland type (Tahara et al., 2011; Sioen et al., 2016a).

No.	Land use type	Indicator [kg/m2]
1	Allotment	4.16
2	Experience	6.91

The proportion of each vegetable in the total production of allotment and experience farms was also estimated based on the same samples.

Finally, the total production (P) of vegetable i from farm type (k) was estimated,

$$P_i = x_i \sum_{k=1}^{f} A_k Y_k \tag{4}$$

where:

x_i is the proportion of vegetable i [-];

A_k is the area of farm type k=1...f [m2]; and

Y_k is the yield of farm type k=1…f [kg/m2].

For both Methods I and II, the production by vegetable was estimated throughout the year by equally distributing the annual production across the harvest periods. This means that each vegetable can be gradually harvested according to the need in time as long as it is within its harvesting period. In addition, the total production [t] was developed by aggregating the vegetable production derived from Methods I and II. To do so, a harvesting schedule was developed with data from literature (Satoshi, 2009) for vegetables grown in the study site. Place specific data is important because climatological and geographical conditions of the site and the type of vegetables grown can have an influence on the nutritional self-sufficiency. Some vegetables had multiple growing seasons. The schedules classified months in three time periods (beginning, middle, and end) according to the seeding, planting, growing, and harvesting periods, which was adopted in the present study. This resulted in 36 time periods for one year, each consisting of 10.14 days. The harvest periods are categorized according to the growing seasons as shown in Fig. 24.

Time / Item	Spring						Summer												Fall						Winter											
	Mar		Apr			May			Jun			Jul			Aug			Sep			Oct			Nov			Dec			Jan			Feb			M.
Cabbage	2	2	2	3	3	3	3	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	2	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	0
Broccoli	2	2	2	2	3	3	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	2	2	2	3	3	3	3	4	4	4	4	4	4	0	0	0	0	0	0	0	0
Soybeans	0	0	0	0	1	3	3	3	3	3	3	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Radishes	0	0	1	1	1	1	3	3	3	3	3	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	3	3	3	3	4	4	4	4	4	0	0	0	0	0	0	0	0	0
Potato	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3	3	3	3	3	3	4	4	0	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Sweet corn	0	0	0	1	1	1	1	1	1	1	1	4	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Green onion	0	1	1	3	3	3	3	3	3	3	2	2	2	2	2	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spinach	1	1	1	1	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	4	4	4	4	4	4	4	4	4	0	0	0	0	0	0	0
J.M. spinach	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0	0	0	0	0	0	0
Carrots	1	1	1	1	1	3	3	3	3	3	3	4	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	0
Taro	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sweet potato	0	0	0	0	0	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tomato	1	0	0	2	2	2	2	3	3	3	4	4	4	4	4	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cucumbers	0	0	0	0	0	2	2	3	3	4	4	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eggplants	0	0	0	0	2	2	2	0	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	1	1	1	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pumpkin	0	1	1	1	2	2	2	3	3	3	3	4	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potherb mustard	0	0	0	0	0	0	0	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chinese cabbage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	2	3	4	4	4	4	4	4	4	4	4	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Podded peas	3	3	3	4	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Strawberry	3	3	3	3	3	3	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Turnip	1	1	1	1	1	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	3	4	4	4	4	4	4	0	0	0	0	0	0	0	0	0
Mountain asparagus	0	0	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	3	3	3	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rapeseed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Green pepper	1	1	3	3	2	2	2	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	1	1	1	1
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Haricot bean	1	1	2	2	2	3	4	4	4	4	4	4	4	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Burdock root	4	4	4	4	4	4	4	4	4	4	4	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Onion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3
	3	3	3	3	3	3	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lettuce	1	2	2	2	2	3	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	2	3	3	4	4	4	0	0	0	0	0	0	0	1	1	1

Figure 24. Planting and harvesting schedule by vegetable and season (Satoshi, 2009). Each month was divided in three time periods (beginning, middle, and end). J.M. spinach: Japanese mustard spinach. Legend: 0 = Nothing; 1 = Seeding; 2 = Planting; 3 = Growing; 4 = Harvesting.

3.2.2. Step 2: Conversion of vegetable weights to nutrients

The Ministry of Health, Labour and Welfare (MHLW) of Japan conducts an annual National Health and Nutrition Survey that lists the food sources from which dietary nutrients in Japanese diets are derived (MHLW, 2015). The 2015 survey lists 29 nutrients from several food sources. Nutrients for which fruits and vegetables contribute more than

20% of the total consumption were analyzed in the present chapter. Furthermore, The Kagawa Nutrition University Publishing Division provides a list of nutrient content and average refuse rates of vegetables from common preparation and cooking methods in Japan. This data was retrieved from the 7th edition of the Tables of Food Composition (Kagawa, 2016). The estimated refuse was subtracted, and multiplied by the remaining vegetable matter for each time period for each of the identified nutrients. This supplies us with the amounts by vegetable of each available nutrient in the respective time section. Finally, the nutrients provided by all vegetables at each time section were then totaled.

3.2.3. Step 3: Self-sufficiency

Estimates of self-sufficiency rates were extrapolated from recommended dietary allowances and population statistics of the study area. Recommended dietary allowances were taken from a list of per capita daily dietary reference intakes for Japan developed by the Japanese MHLW. This list is updated every 5 years based on the latest scientific research (Ministry of Health Labour and Welfare, 2015). The recommended dietary allowance was retrieved, or if unknown, the adequate intake of the selected nutrients per age group and gender for the year 2015 were obtained. The nighttime population is the highest population in the ward as a large number of people commute to the central business district of Tokyo. According to the Statistics Bureau of Japan (2000) there is a 77.5 ratio daytime to nighttime population in Nerima ward, making the nighttime population the worst case scenario. Population statistics by age and gender were acquired for the nighttime population from the portal site of Official Statistics of Japan developed by the Ministry of Internal Affairs and Communications (2015). The population was then categorized according age and gender specifications established by the Dietary Reference Intakes for Japanese (2015) (MHLW, 2015) as shown in Table 2 (Statistics Bureau of Japan, 2016a). Population statistics are available by one-year age groups. The first life year of both males and females was further divided into two groups for compatibility with dietary reference intakes. Children younger than 5 years old were excluded from the self-sufficiency calculation of dietary fibers because of the lack of scientific evidence on the reference intake for this group. Besides these factors, previous studies reported a higher nutrient demand for certain life stages (e.g. when pregnant or lactating) (Morita et al., 2013). However, a low fertility rate of 1.24 was observed in the case study (TMG, 2017), which means that this target group is limited, and there was no data available for pregnant and lactating women in Nerima, which is crucial for the nutrient demand. Additionally, pre-disaster diseases that can cause variations in nutrients suggestions - the case of diabetes patients - were not considered because of limitations in the data availability. However, conducting the estimations with the available data as shown in Table 8 can still produce the results that are in line with the aim of the study. The total requirements for the remaining nutrients were calculated for each age category and gender by multiplying the reference intakes for Japan with the population.

Table 8. Population by age and gender in 2015 in Nerima ward (Statistics Bureau, 2016a).

Age group	Total	Male	Female
0-5 months*	2935	1497	1438
6-11 months*	2935	1497	1438
1-2 years	11543	5906	5637
3-5 years	16930	8720	8210
6-7 years	11381	5888	5493
8-9 years	11046	5732	5314
10-11 years	11221	5717	5504
12-14 years	18115	9370	8745
15-17 years	18642	9559	9083
18-29 years	101874	49695	52179
30-49 years	225450	113735	111715
50-69 years	168816	84328	84488
70+ years	116008	47393	68615
Unknown**	4814	2572	2242
Total	721709	349037	367858

*Equally divided based on data 0-11 months dataset, **Not utilized in present chapter.

Self-sufficiency over the course of the year was estimated by dividing the produced nutrition by the reference consumption of each time section. The following equation was developed for the estimation of self-sufficiency:

$$\eta_{j,t} = \frac{\sum_{i=1}^{v} h_{i,t} P_i (1 - r_i) N_{i,j}}{C_j} \quad (5)$$

where:

h_t is the harvest rate per time section t [-];

P_i is the production of vegetable i = 1…v [kg];

r_i is the refuse rate of each vegetable [-];

$N_{i,j}$ is the nutrient content per vegetable [mg/kg]; and

C_j is the reference consumption of nutrient per time section [mg].

Resulting self-sufficiency rates by nutrient were compared with the self-sufficiency rate in vegetable weight, which was estimated based on the targeted per capita recommendation of mean daily intake of vegetables (350g) set by the Japanese MHLW, (2016).

3.2.4. Setting

Nerima ward is second most populous of the 23 special wards (urban areas) of Tokyo's prefecture, with 15,019 people/km² (2015) over a surface area of 48.08 km^2. Despite Japan's population decline, the population in the ward grew from 716,124 residents in 2010, to 721,709 residents in 2015 (Statistics Bureau of Japan, 2016a). Some 222,650 residents make their living in the tertiary industry, but only 1,180 professionals in the primary industry and 43,009 in the secondary industry (Statistics Bureau of Japan, 2016a). Nerima ward has a long history with farming. For example, the family of Shiraishi Y. has been farming in the ward since Edo period (1603 – 1868) (Y. Shiraishi, 2001) and there are farmers that specialize in vegetable species primarily grown in the ward during that time period (e.g. Nerima Daikon (Yokohari & Amati, 2005), which is a type of radish) (Nerima ward, 2010). The ward is one of few that has its own UA section. Registered farmers can receive subsidies for their investments, a platform for knowledge exchange, and promotion during public events (e.g. farming historical species is supported by Nerima's UA section) (Nerima ward, 2010). The ward was selected because of its substantial area of agricultural land in densely populated areas and its general contribution to UA in Tokyo (Yagasaki & Nakamura, 2008a).

Nerima's large share of UA within Tokyo's special wards is the result of its slower urban growth rate compared to other wards in the sixties (Sorensen, 2002). Located on the edge of the upland plateau, Nerima's soil is good for vegetable production (Kurita, Yokohari, & Bolthouse, 2009), which motivated farmers to protect their farmlands. The government established the City Planning Act in 1968 (Yagasaki & Nakamura, 2008b) and designated open spaces (including farmlands) in Tokyo as Urbanization Promotion Areas (UPA). These areas were intended for development within the next 10 years, however, many places remained UA because the urban growth rate slowed down. UPA lands were taxed as urban land uses, which caused a substantial financial burden for remaining farmers. This was also the case for UA in Nerima.

Under the City Planning Act, the Productive Green Land Act was enacted in 1974 and revised in 1992 (Yagasaki & Nakamura, 2008b). The act reduced land taxations for farmers if a 30-year commitment to UA was made. It successfully enabled farmers to continue their activities by delaying development, simultaneously protecting UA. This resulted in the large presence of remaining agricultural land uses in the outer belt of Tokyo's 23 wards as can be seen in Figure 25, which is based on the content of Chapter 2 Figure 8. Despite Nerima's important ranking in UA, the number of people engaged in professional agricultural activities has decreased from 1890 people in 1970 to 714 people in 2005, a decrease of more than 60% over a period of 25 years. However, the decline has stabilized at 642 people since 2010 (Statistics Bureau of Japan, 2015). Nerima ward today, contains the highest number of UA area (180.23ha) in the 23 special wards of Tokyo (TMG, 2016a).

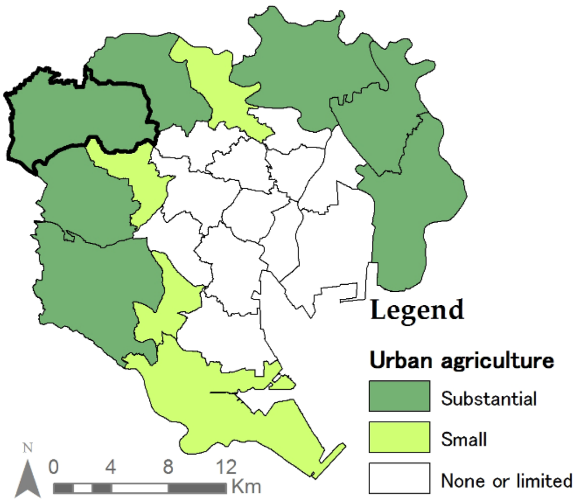


Figure 25. Tokyo's 23 special wards where UA can be found (Nerima ward bolded) (TMG, 2015b).

3.2.5. Subjects

The Nerima ward residents (categorized according to gender) were the subjects of this study. 4,814 people (0.67%) of unknown age (Statistics Bureau of Japan, 2016a) were excluded from the study because age is an important factor in estimating the reference consumption of nutrients. Life stages (e.g. pregnant, or lactating) and health conditions (diabetic), which can affect the reference consumption for those individuals were not considered in the present study because no data was available for the population. Despite these limitations, the estimation can provide a general outcome for the entire case study population. The numbers of subjects totaled 716,895 people.

3.3. Results

Fig. 26 shows the spatial identification (Step 1, Method II) of 53 allotment UA plots (7.38ha) and 26 experience UA plots (7.32ha) in Nerima ward. The figure also shows the distribution of the 1,396 professional UA farms (180.23ha) used in Method I. The average size of an UA plot in the ward was determined as 1321.59m^2. The yields estimated by Methods I and II were 4,776 tons and 884 tons, respectively, totaling to 5,660 tons. Table 3 shows the yield of each vegetable obtained from governmental data by Method I. By omitting the refuse (Kagawa, 2016) and factoring in the number of harvest periods, the harvests ready for consumption in each time period were added further quantifications in Step 2. The same procedure was applied for estimating production from hobby UA, using data from the previous studies in Method II. The results are shown in Table 9 and 10.

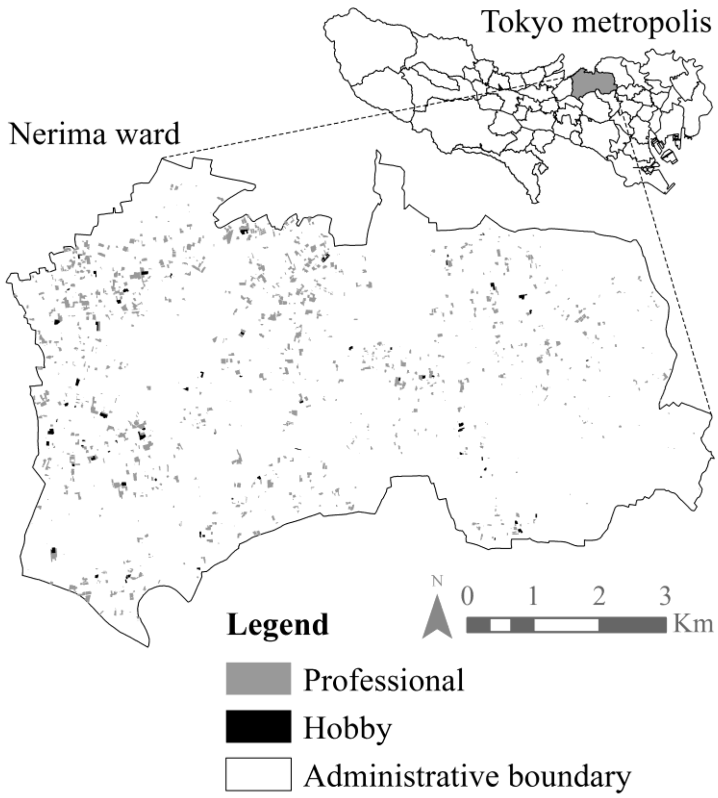


Figure 26. Urban agriculture in Nerima ward, Tokyo. Hobby UA consist of both allotment and experience UA. Basemap: TMG (2016).

Table 9. Harvest per vegetable and net weight per time period according to Method I.

No.	Vegetable item	Harvest [t] (TMG, 2015)	Refuse [%] (Kagawa, 2016)	Harvest [periods]	Harvest per period [t]
1	Cabbage	1973.00	15%	16	104.82
2	Radishes	557.00	10%	9	55.70
3	Tomato	307.00	3%	10	29.78
4	Eggplant	255.00	10%	14	16.39
5	Carrot	217.00	3%	18	11.69
6	Potato	211.00	10%	6	31.65
7	Chinese cabbage	198.00	6%	9	20.68
8	Broccoli	153.00	50%	11	6.95
9	Green onion	147.00	40%	11	8.02
10	Japanese mustard spinach	119.00	15%	25	4.05
11	Soybeans	111.00	45%	2	30.53
12	Spinach	86.00	10%	12	6.45
13	Cucumbers	84.00	2%	7	11.76
14	Sweet corn	76.00	50%	6	6.33
15	Turnip	73.00	9%	11	6.04
16	Sweet potato	72.00	9%	5	13.10
17	Taro	61.00	15%	5	10.37
18	Pumpkin	24.00	10%	6	3.60
19	Strawberry	10.00	2%	3	3.27
20	Green pepper	10.00	15%	14	0.61
21	Potherb mustard	8.00	15%	15	0.45
22	Podded peas	6.00	9%	6	0.91
23	Mountain asparagus	6.00	35%	4	0.98
24	Haricot beans	6.00	3%	12	0.49
25	Rapeseed	3.00	0%	20	0.15
26	Burdock root	3.00	10%	18	0.15
	Total	4776.00			384.91

Table 10. Harvest per vegetable and net weight per time period according to Method II.

No.	Vegetable item	Harvest [t]	Refuse [%] (Kagawa, 2016)	Harvest [periods]	Harvest per period [t]
1	Radishes	203.39	10%	9	20.34
2	Chinese cabbage	99.20	6%	9	10.36
3	Tomato	83.88	3%	10	8.14
4	Cabbage	69.08	15%	16	3.67
5	Cucumbers	60.08	2%	7	8.41
6	Potato	58.96	10%	6	8.84
7	Taro	50.08	15%	5	8.51
8	Carrots	44.95	3%	18	2.42
9	Podded peas	43.13	9%	6	6.54
10	Green onion	31.85	40%	11	1.74
11	Pumpkin	26.74	10%	6	4.01
12	Broccoli	26.64	50%	11	1.21
13	Eggplants	20.90	10%	14	1.34
14	Onion	19.14	6%	4	4.50
15	Spinach	17.43	10%	12	1.31
16	Sweet potato	13.63	9%	5	2.48
17	Green pepper	8.33	15%	14	0.51
18	Lettuce	6.28	2%	7	0.88
	Total	883.70			95.21

Table 11 shows results regarding estimated weights and nutrients. The weight-based estimations from the recommended per capita vegetable intake and production in Nerima ward indicate a self-sufficiency rate of 6.18%. This weight-based estimation also enables comparison with previous self-sufficiency studies. The nutrient-based results were estimated with the reference intake per nutrient. Nine nutrients met the selection criteria described in Step 2. The required intake of these nutrients for the entire population of Nerima was converted to kilograms (Table 8). The self-sufficiency rates estimated according to each Method in step 3, reflect the reference intake per nutrient. Nerima was most self-sufficient in vitamin K, vitamin C, folic acid, dietary fiber, and potassium derived from vegetables. Lower levels of self-sufficiency were found for vitamin B6, vitamin A, vitamin E, and calcium also derived from vegetables. The average nutritional self-sufficiency rates according to Methods I and II were 2.48% and 0.38%, respectively. These combine to the aggregated average nutritional self-sufficiency rate of 2.86%. Although it had a small representation compared to that of professional UA, hobby UA still contributed to 0.98% of the ward's vegetable self-sufficiency. Fluctuations were also found throughout the seasons based on utilized species and their resulting harvests shown in Table 12.

Table 11. Annual required, available nutrients, and self-sufficiency rates.

		Available [kg]		**Self-sufficiency [%]**		
Name	**Required [kg]**	**Method: I**	**II**	**I**	**II**	**I & II**
Vegetables in weight	91,584,869.00	4,776,000.00	883,701.00	5.21	0.96	6.18
Dietary fiber	4,552,058.45	75,493.58	13,801.21	1.66	0.30	1.96
Potassium	686,243.03	10,338.25	2,160.88	1.51	0.31	1.82
Calcium	171,473.72	1,441.21	196.97	0.84	0.11	0.96
Vitamin C	24,565.73	1,174.72	176.10	4.78	0.72	5.50
Vitamin E	1,566.47	13.73	3.98	0.88	0.25	1.13
Vitamin B6	321.67	4.20	0.77	1.30	0.24	1.54
Vitamin A	190.11	2.39	0.53	1.26	0.28	1.54
Folic acid	58.34	2.65	0.36	4.54	0.61	5.15
Vitamin K	37.03	2.06	0.22	5.57	0.58	6.15
Nutrient average				2.48	0.38	2.86

Table 12. Average self-sufficiency by method and season.

Name	Method I [%]				Method II [%]			
	Spring	**Summer**	**Fall**	**Winter**	**Spring**	**Summer**	**Fall**	**Winter**
Vegetables in weight	0.11	2.60	2.01	3.78	0.09	0.48	0.39	0.42
Dietary fiber	0.06	1.95	1.40	2.29	0.08	0.41	0.34	0.29
Potassium	0.07	1.79	1.57	1.91	0.03	0.42	0.45	0.28
Calcium	0.06	0.84	0.70	1.30	0.02	0.13	0.12	0.15
Vitamin E	0.05	1.25	1.21	0.75	0.05	0.47	0.29	0.12
Vitamin A	0.07	1.42	0.92	1.86	0.03	0.39	0.15	0.36
Vitamin K	0.33	4.74	4.27	9.66	0.15	0.53	0.57	0.86
Folic acid	0.18	4.98	3.53	6.78	0.15	0.67	0.69	0.75
Vitamin C	0.17	4.97	3.33	7.63	0.29	1.01	0.60	0.70
Vitamin B6	0.04	1.45	1.15	1.88	0.03	0.33	0.28	0.23

The self-sufficiency rates for the nine selected nutrients and vegetables are shown in Fig. 27 (Method I) and Fig. 28 (Method II). The figures are based on the three time periods per month as shown in the harvest table produced in Step 1. Variations in self-sufficiency are present because of two main factors: 1) type of nutrient; 2) time of year. According to the nutrient scale from professional UA in Figure 27, vitamin C showed the highest self-sufficiency compared to other nutrients while vitamin E was found to have the lowest rates. In Figure 28, the highest self-sufficiency was also vitamin C, however, due to the variation in vegetables cultivated (as shown in tables 8 and 9), calcium was the lowest. Winter vegetables are harvested by the end of February, resulting in the lowest self-sufficiency in March and beginning of April. According to the harvest table, these times are mostly planting periods. The highest self-sufficiency was observed from July to end of August (summer harvest) and from the end of October to beginning of December (winter harvest). Although professional UA contributed more in sheer amount because of its larger presence, hobby UA contributed more with less land and experienced a more constant supply than professional farms.

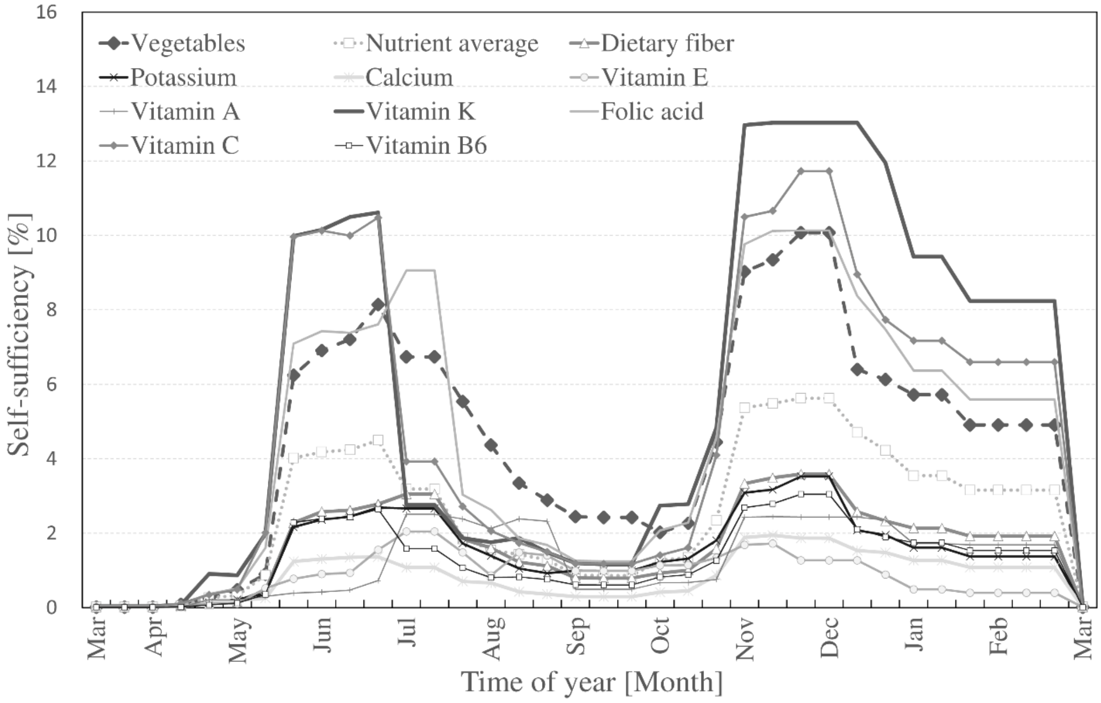


Figure 27. Self-sufficiency in Nerima ward from Method I.

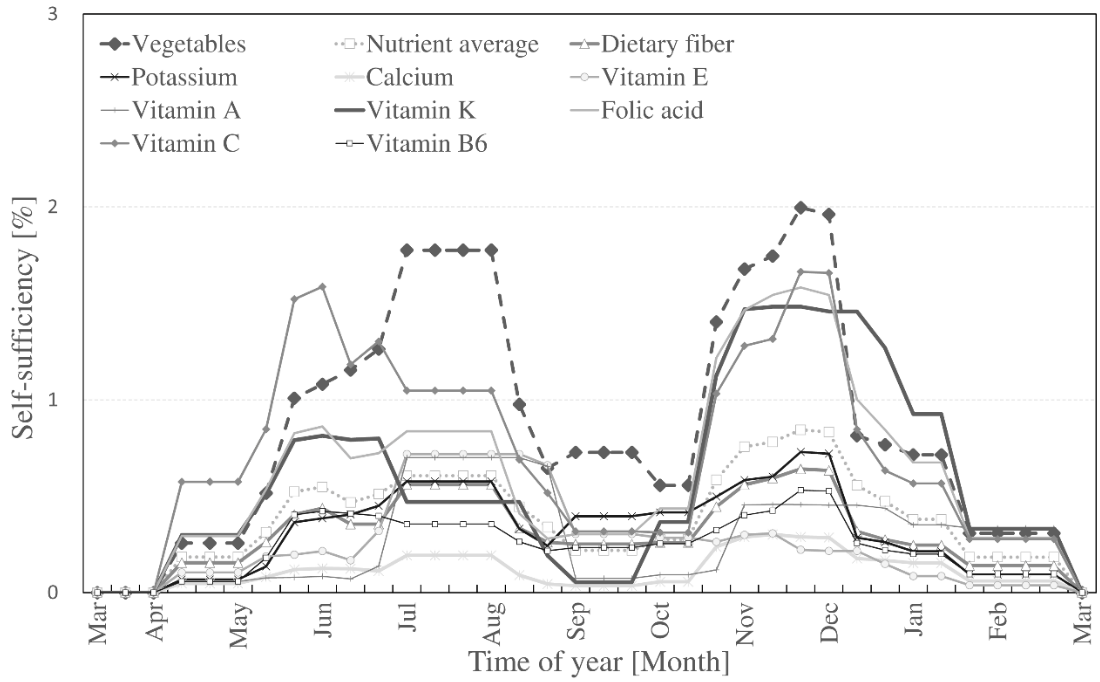


Figure 28. Self-sufficiency in Nerima ward from Method II.

Finally, the combined vegetable and nutritional self-sufficiency rates from Methods

I and II are shown in Fig. 29. Variations throughout the year can be attributed to fluctuations in the planting and harvesting seasons (Fig. 24). Vegetable weight-based self-sufficiency averaged 5.24% across the year, higher than the nutritional self-sufficiencies. The hobby UA analyzed with Method II contributed to a more stable supply of UA vegetables and nutrients in Nerima ward. Averages in self-sufficiency were found for vitamin K (6.15%), followed by vitamin C (5.50%), folic acid (5.15%), dietary fiber (1.96%), and potassium (1.82%), vitamin A (1.54), vitamin B6 (1.54%), vitamin E (1.13), and calcium (0.96%).

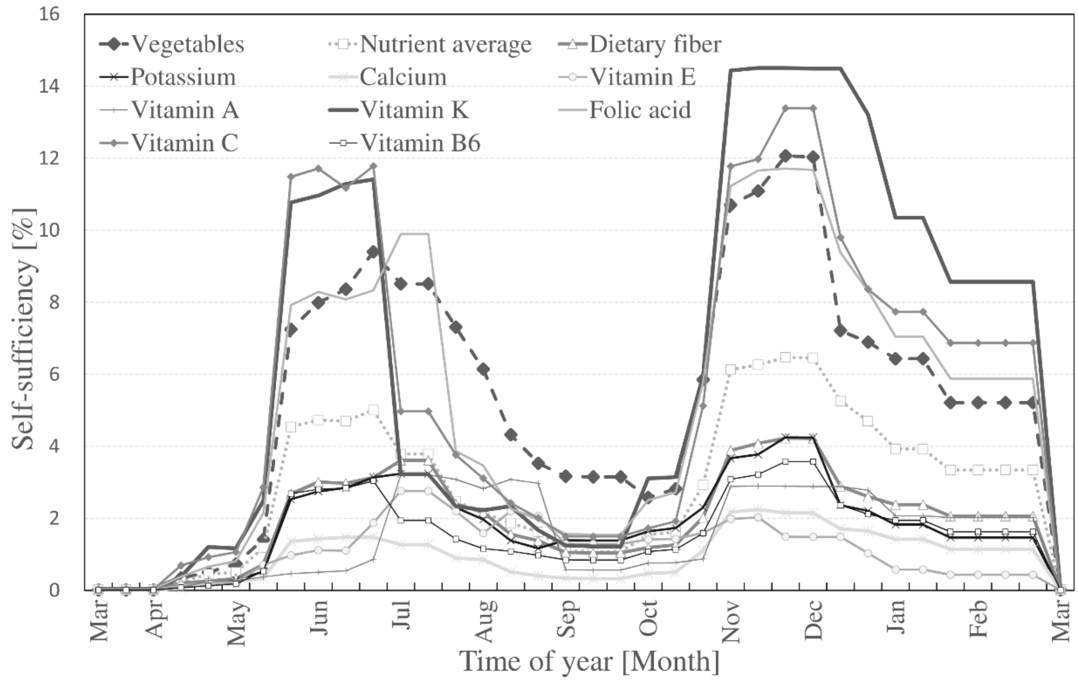


Figure 29. Aggregated self-sufficiency in Nerima ward from Method I and II.

3.4. Discussion

UA contributed on to the self-sufficiency of the nine nutrients selected in this case study. In other words, depending on the season and nutrient, about 20,503 people out of 716,895 people can be self-sufficient in nutrients from UA in the present case study. Step 1 of the analysis, estimated production from professional UA using governmental data (Method I) and production from hobby UA (allotment, experience farming) by conducting a spatial analysis (Method II). To understand the impact of this study, we discuss the results in four sections as follows: (1) comparison with other case studies and contextualization of the results, (2) impact and target of nutritional self-sufficiency for post-disaster situations, (3) the role of UA in disasters, and (4) limitations and future work.

Comparison with other case studies and contextualization of the results

We postulate that the high self-sufficiency rate in Nerima compared to previous weight-based studies (Grewal & Grewal, 2011) may very well be caused by the active engagement of the local government in promoting and subsidizing UA activities. Specifically, the local government subsidizes farmer's investments in new facilities and provides a unique platform for knowledge exchange and quality improvement - as the municipality is one of the few in the country to have its own UA section. In addition, investments by innovative farmers in Nerima, creating viable businesses (Yagasaki & Nakamura, 2008b), led to the creation of experience farms. Shiraishi Y. (2001) (Y. Shiraishi, 2001) established this new type of farming, generating his income by providing agricultural experiences to urbanites rather than through professional agricultural production (Nerima ward, 2016a; Y. Shiraishi, 2001; Sioen et al., 2016a). Experience UA proved to have higher yields compared to professional or allotment farming (Tahara et al., 2011). Further democratizing UA can thus increase the self-sufficiency in the case study area. The overall popularity of UA for education, leisure, and the self-cultivation of food can be attributed to a high number of public initiatives and events (e.g. annual radish rally or blue berry picking events (Nerima ward, 2010)) (B. M. Shiraishi, 2001). These led Nerima to become the Tokyo prefecture municipality with the largest share of hobby farms (Sioen et al., 2016a).

Though numerous UA studies have estimated vegetable self-sufficiency, we found none that estimated nutritional self-sufficiency. For example, Grewal and Grewal (Grewal & Grewal, 2011) conducted a study in Cleveland, USA and found 1.7% self-sufficiency for fresh produce, despite its lower population density in the city (2241 people/km^2 (United States Census bureau, 2010)) compared to Nerima (15,019 people/km^2 (Statistics Bureau of Japan, 2016a)). The result drew from annual yield and consumption of UA produce. For comparison purposes, we applied the same weight-based analysis to the present case study and discovered a 6.18% annual vegetable self-sufficiency. We also found that the weight-based self-sufficiency varied throughout the year (average after subtraction of the refuse: 5.24%). These results are higher than previous findings because of high yields and urban planning policies protecting agricultural activities in Japanese cities (Tsubota, 2007).

Prior studies failed to estimate vegetable production in different times of the year (Grewal & Grewal, 2011; Sioen et al., 2016a). Because disasters can affect communities at any time (Altay & Green, 2006), knowledge of nutrition availability from UA at any given point of year will lead to improved disaster preparedness and speedier emergency food provision. We have thus estimated the contribution of UA to the nutritional self-sufficiency throughout the year. The present study corroborates that vegetable yields fluctuated during the year, effecting the corresponding self-sufficiency rates. The highest average self-sufficiency rates from combining Methods I and II were in winter (4.20%), followed by summer (3.08%), and fall (2.40%). Little to no self-sufficiency was discovered in spring (0.21%). Indeed, nutrient self-sufficiency at the time of the March 11th Great East Japan Earthquake in the present case study was a critically low as 0.02%, putting public health at risk. At that time, the rations in the Tohoku area (northeast Japan) were already low from typhoons, flooding's, and eruptions of active volcanoes that occurred before the earthquake. Furthermore, damage of the main supplement provider exacerbated the nutrition crisis at the time (Amagai et al., 2014). These results confirm the vulnerability of the area during times of low self-sufficiency and potentially increased resilience during times of higher self-sufficiency.

Impact and target of nutritional self-sufficiency for post-disaster situations

The present chapter shows the potential value of UA as a source of disaster preparedness food. When considering the total population, the mean nutritional self-sufficiency was found to be 2.86%. However, this result has a bigger impact when targeting evacuees of a disaster. A simulation in Tokyo conducted by TMG (2016b) predicted that a magnitude 7.3 earthquake under Tokyo Bay North Area (worst case scenario) would force 3,390,000 residents to evacuate, and be in need of food and shelter by the next day. This is 26% of the city's population that requires food. If this ratio of potential evacuees in the first phase after a disaster (Nakazawa & Beppu, 2012) (up to three days depending on the scale and location) is applied to the present study area, the mean nutritional self-sufficiency would be 11%. This means that 20,503 evacuees can have immediate access to sufficient nutrients from within the disaster struck area. As this research has indicated, self-sufficiency levels vary by nutrient and time of year. Nutrient self-sufficiency levels range from 23.65% in vitamin K to 3.67% in calcium. Seasonally, the highest mean nutritional self-sufficiency according to this estimation would be in winter (16.50%) and the lowest in spring (0.97%). However, survivor's primary need during this first phase after the disaster is in carbohydrates, which is already provided by conventional emergency food (Nakazawa & Beppu, 2012).

Nutritional self-sufficiency becomes crucial during the mid-term phase (days - months) after a disaster to avoid gastrointestinal symptoms and cardiovascular diseases due to dependence on carbohydrate based emergency foods (WHO, 2004). Greater numbers of evacuee's move from the affected area during this phase. Previous studies highlighted higher nutritional needs of vulnerable populations (e.g. young children, elderly, patients, pregnant, and lactating women (Tsuboyama-Kasaoka & Purba, 2014)), which is a fraction of the 26% target ratio set in the estimation above. Due to the lack of data on life stages, health conditions, and migration patterns of the population after a disaster, we estimated the nutritional self-sufficiency of children (0-14 years old) and the elderly (50+ years old) based on the simulation by TMG for the mid-term phase after a disaster. The mean nutritional self-sufficiency for 96,442 people in Nerima was found to be 22.71% (21,902 people), about double that of the previous phase, and still underestimated due to the described limitations in data. The highest from the selected nutrients according to this estimation would be 33.34% in winter and the lowest 1.64% in spring. Again, the self-sufficiency rate was highest for vitamin K (48.50%) and lowest in Calcium (7.31%), but with vitamin K exceeding the necessary level for half of the evacuees 16 out of 36 time periods seen in Figure 24.

UA can play a more important role depending on the area of the disaster. During the expansion of Tokyo, a large number of wooden rental houses (Moku-chin) was built in areas surrounding the city to meet the increasing housing demand (Sorensen, 2002; Sorensen, 2011). In these areas, basic infrastructure was often disregarded due to a failure to adopt planning concepts (Sorensen, 2002). These areas are characterized by narrow roads with limited connectivity, vulnerable to disasters (Sorensen, 2011) and difficult to provision (Sorensen, 2002). In contrast, the inner core of the city was planned with infrastructure and wide roads. Emergency food can be distributed from rations provided by large corporations. Therefore, UA has a greater importance as disaster preparation food in the wards characterized with Moku-chin (Fig. 30). Figure 30 indicates that UA could indeed function as a potential food source in these vulnerable areas.

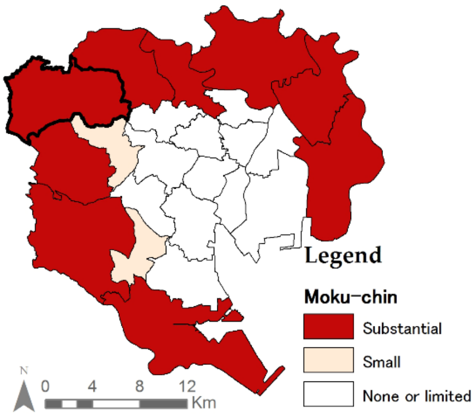


Figure 30. Vulnerable wards with high-densities of Moku-chin (characterized by narrow roads, causing greater risks in emergency situations (Andre Sorensen, 2011)) in the 23 special wards of Tokyo (Nerima ward bolded) (TMG, 2016a).

UA can play a further role in long-term recovery processes (months - years) (Nakazawa & Beppu, 2012). The conventional distribution system would be recovering during this phase. The primary role of UA during this phase shifts from a source of nutrients to a source of survivors' self-esteem and psychological health (K. H. Brown & Jameton, 2000).

Role of urban agriculture in disasters

The present chapter confirms the valuable role of UA (Gudzune et al., 2015) to complement emergency food provisions in disaster preparedness as a local source of food with crucial nutrients (Nakazawa & Beppu, 2012). UA can complement survivor diets with nutrients beyond those in provided rations and external emergency foods which are rich in carbohydrates (Inoue et al., 2014). This diversified diet with vegetables mainly providing dietary fiber can help prevent several health issues previously reported in post-disaster health studies around the world (Bassett, 2010; Centers for Disease Control and Prevention, 2006; Tsuboyama-Kasaoka & Purba, 2014; UNICEF, 2015). Studies link higher intakes of dietary fiber with numerous health benefits (Anderson et al., 2009): the prevention of gastrointestinal symptoms, higher blood glucose levels, and higher blood pressure (Inoue et al., 2014). Additionally, a dearth of vegetable consumption can lead to vitamin deficiencies (Amagai et al., 2014), and non-specific complaints (Okuda et al., 1996), such as colds and coughs (Tsuboyama-Kasaoka & Purba, 2014). Overall, there is a consensus that vegetables are beneficial for health (Slavin & Lloyd, 2012). Though evidence is limited, some reports mentioned the positive role of UA in post-disaster situations (Fao, 2011) and indicated that UA may very well have significant positive health outcomes during post-disaster situations.

Large disasters cause a variety of mental health disorders in disaster survivors (Suzuki et al., 2011). The World Health Organization reported that UA can play a role in its relief: "*Supporting self-reliance is important to enhance the capacities and self-esteem of the affected population and may contribute to reducing dependence on food aid*" (WHO, 2004) (p. 34). The day-to-day benefits of physical exercise and social interactions with UA practices can therefore lead to better health during recovery periods. A study conducted in the United Kingdom revealed a significant correlation between consumption of healthy foods and perceived stress and depression (El Ansari, Adetunji, & Oskrochi, 2014). Although further research on post-disaster situations is needed, food from UA can help alleviate such mental disorders.

UA can improve disaster awareness, as engaged populations can increase disaster preparedness. An increase in the proliferation of hobby UA can result from this engagement and lead to more diverse food sources that meet the local needs and preferences (Wilkins et al., 2015). The strengthened presence of UA can also reduce the hurdle of food distribution processes in heavily affected areas with large populations. It was reported after the Great East Japan Earthquake that smaller emergency shelters might have had improved nutritional conditions. Nutrition conditions were best where evacuees were few in number and gas supply was quickly restored (Tsuboyama-Kasaoka et al., 2014). In the case of densely populated megacities, complex utility systems and narrow roads (A Sorensen, 2000), such as those in the present study area, will undoubtedly cause the distribution of meals to be even more challenging. Tis is in comparison to areas with relatively lower population densities such as those affected in northeastern Japan in 2011. Therefore, local distribution and consumption of fresh produce from UA can complement meals among a larger number of beneficiaries and increase the nutrient intake across heavily affected areas.

The Nerima ward government has been exploring UA benefits for local provisioning by improving disaster awareness, and neighborhood familiarity with farmers for evacuation and sourcing food in emergencies. The local government took the initiative to engage professional and hobby farmers in a yearly disaster drill as an additional to help neighboring residents in disaster preparedness (Fig. 31). During the drill, residents from the neighborhood familiarize themselves with the UA areas. Post-disaster studies have reported damages to utilities (electricity, gas, and water), which proved problematic for cooking (Amagai et al., 2014). Vegetables grown in Nerima ward, such as cabbages and carrots, can be consumed raw in emergencies. However, for certain nutrients, steaming or cooking the vegetables minimizes the nutritional loss compared to other cooking methods (Rumm-Kreuter & Demmel, 1990). Cooking can also increase dietary fiber content per gram in some vegetables when heating removes excess water from the vegetables (Slavin & Lloyd, 2012). Local governments (including Nerima) have already prepared portable gas cookers for when utilities are unavailable (Tsuboyama-Kasaoka et al., 2014). Thus, this can lead to improving nutritional intake in times of disasters.

Figure 31. Disaster drill held in Nerima ward. (**a**) Urban farmland with a high diversity in crops, (**b**) Farmer and volunteers preparing soup with fresh vegetables from the farm in a portable gas stove, (**c**) Rice and crackers provided by the municipality as emergency food with freshly made soup containing vegetables from the farm, (**d**) People from the neighborhood familiarizing with each other and the farmer (By author Nov., 2016).

<u>Limitations and future work</u>

The present chapter has several limitations. Firstly, the nutrient content in some vegetables varies according to the harvest season. However, because such details were unavailable for all vegetables (Kagawa, 2016), only average contents were used in the current study. Secondly, the production from professional UA in Method I came from market-based government statistics that exclude direct sales and self-consumption (TMG, 2015b). Therefore, the actual production and corresponding self-sufficiency from Method I could be higher in reality. In contrast, the production from hobby UA in Method II may be overestimated because few studies have weighed the vegetable production from hobby UA (Tahara et al., 2011). Specifically, the indicators used for the estimations were drawn from five samples of allotment and experience farms. These samples were pioneering cases at the time. Thirdly, potential damage from disasters to farmlands needs to be considered in future studies. Previous earthquakes in Japan damaged farm equipment and buildings, but reported damage to vegetable fields is limited. Fourthly, previous post-disaster studies reported that pregnant and lactating women were groups in specific need for sufficient nutrients (Morita et al., 2013). Also, survivors diagnosed with health issues before a disaster (e.g. diabetes patients) experienced higher risks compared to their healthy counter-parts. Due to data limitations, these factors were not incorporated in the present study. Fifthly, the nutritional self-sufficiency was estimated with the dietary reference intake for daily purposes (MHLW, 2015). However, the nutrient requirement during the first and second phase after a disaster could be reduced to the minimum in an emergency situation. Because of the focus on carbohydrates in emergency studies (WHO, 2004), there was insufficient data available to incorporate the minimum requirements of nutrients for the population in the present study. Despite these limitations the study is able to estimate the nutritional contributions of UA for the general public. Lastly, we assumed that all agricultural lands in use are safe from heavy metals and other contaminants, and that the use of chemicals is kept within the government guidelines.

Countries around the world have been discussing self-sufficiency from political standpoint. It is argued that self-sufficiency stands in contradiction to trade agreements (Clapp, 2017), a response to the demand by people for fresh and safe food (Yokohari & Bolthouse, 2011). However, this research shows that food self-sufficiency can increase the resilience of communities. Therefore, local food systems may seem redundant in the face of international trade but are invaluable for disaster preparedness. Future studies should identify a target self-sufficiency rate for each nutrient by simulating different scales of disasters, while maintaining trade agreements. In addition, they should explore the contributions of UA in different areas of the city according to their land use patterns (ratio of urban and agricultural land uses) as well as potential contributions from other lands that are currently underutilized (e.g. vacant land (TMG, 2016a)).

In conclusion, UA has potential to supplement rations and other emergency foods as disaster preparedness food, depending on the time of year. In the present case study, the mean self-sufficiency rates varied according to season (winter (4.20%), summer (3.08%), fall (2.40%), and spring (0.21%)). If contemporary emergency food rations are to prevent diet-caused symptoms among survivors, such rations should be better strategized with local UA availability and the time of year the disaster takes place. The present case study showed variations in the mean self-sufficiency by nutrient (vitamin K (6.15%), vitamin C (5.50%), folic acid (5.15%), dietary fiber (1.96%), potassium (1.82%), vitamin A (1.54), vitamin B6 (1.54%), vitamin E (1.13), and calcium (0.96%)) indicating the importance to address self-sufficiency studies on scale of nutrients. Also, it was discussed that focusing on the vulnerable target groups (age groups 0–14, and 50+) of refugees, the mean self-sufficiency of selected nutrients in the present case study was 22.71%. This study has implications for policies and emergency response strategies around the world to increase the intake and availability of vegetables with crucial nutrients provided by UA during post-disaster situations. The two main findings of this chapter were: (1) UA can provide a valuable contribution to the nutrient provisioning of survivors during different stages after a large disaster; (2) emergency food must be targeted according to the time of year the disaster takes place to meet the needs of survivors (Sioen et al., 2017).

4. INTEGRATED DISCUSSION

4.1. Meaning of the results

The meaning of the results from Chapter 2 and Chapter 3 are discussed in the integrated discussion. These reflect on the originalities of the findings which lead to the policy implications and practical recommendations.

4.1.1. Land use patterns of consumption and production

There is a mismatch between the best-case location of the population's reference consumption (Fig. 9) and that of production (Fig. 10) discussed in Chapter 2. The figures show that urban areas (Type A and B) have higher demands of fruits and vegetables, while these areas have none or the lowest production. Similarly, areas with more open spaces (Type C and D) had a relatively lower demand (reference consumption) because of a lower population density but have a high self-sufficiency when UA was present. When it comes to self-sufficiency from fruits and vegetables, the present study proves that in the inner core of the city, without the presence of farmlands and little potential from other land uses, UA is insignificant. However, areas where there is a larger presence of UA in combination with a lower urban population density, UA can contribute a considerable amount of fruits and vegetables containing valuable dietary nutrition. Conceptually, Figure 32 illustrates the production and consumption demand from urban to rural as was introduced in Figure 4. The illustration shows that the contribution from UA will not be in the inner core of the city but rather in the suburban area where there is sufficient production to meet the demand for consumption in emergency situations.

These factors can still vary depending on the type of fruits and vegetables that are grown on the UA lands. For example, the Potassium found in Cabbage has a mean content of 200mg for every 100g. However, Spinach and Taro contain 690mg and 640mg, respectively (Kagawa, 2016). Cabbage is the main vegetable grown in Nerima ward, therefore, if only the maximization of nutrient content is considered, other species should be recommended to increase the nutritional self-sufficiency on a local scale.

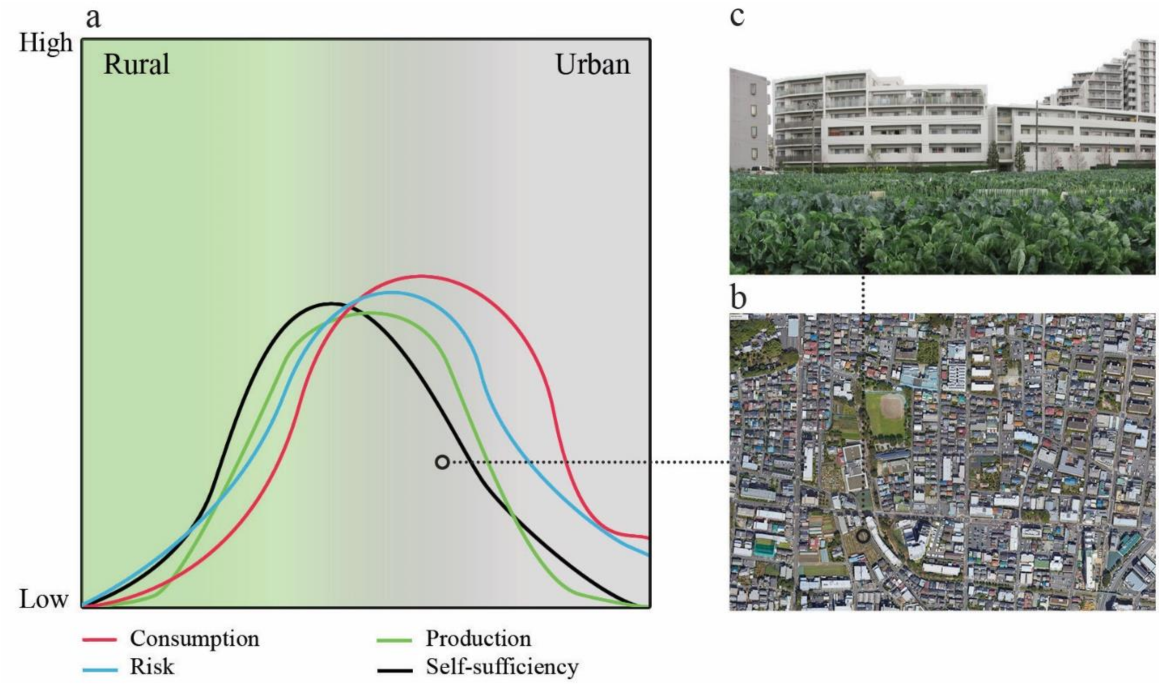


Figure 32. Point where UA contributes according to the concept op consumption and production in mixed land uses. (**a**) Concept drawing by author, (**b**) satellite imagery of Nerima ward Source: Google Earth image a) Feb. 10th, 2016, (**c**) experience farm in Nerima ward (By author Nov., 2016).

When looking at an example of a conceptualization shown in Figure 32 on the scale of Nerima ward, we can see in Figure 33 that the highly populated areas as shown in Appendix A5 can be categorized as more urban areas. Consequently, these areas have lower levels of self-sufficiency in fruits and vegetables. In contrast, there are areas where there is a higher presence of UA and thus has a higher presence of rural land uses. The South East of Nerima ward is an area with a high population density as shown in Appendix A5 and low presence of UA as shown in Figure 7. The area has potential with stable vacant lands, however, currently there are no incentives for land owners to transform their vacant lands into more productive land uses such as for UA activities. The areas where there is more potential because of a relatively high population density and self-sufficiency are shown in Figure 33 (light-green). Therefore, strategies can be applied to target the utilization of UA for post-disaster situations in those areas that overlap with the aggregated risk map.

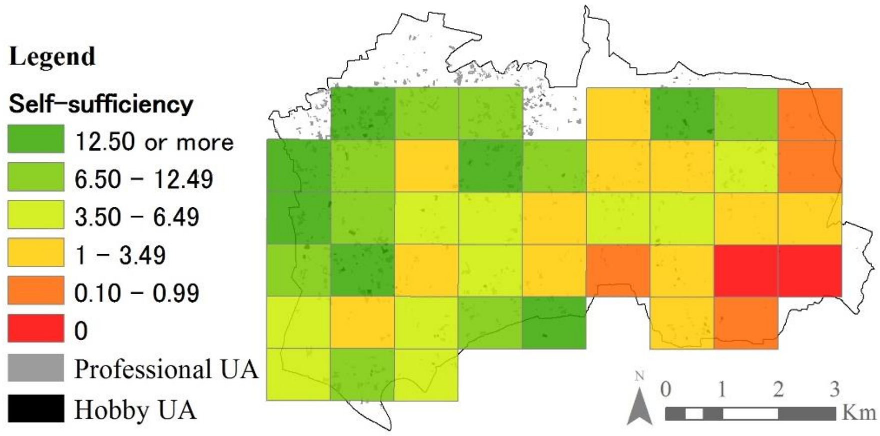


Figure 33. Self-sufficiency analysis in Nerima-ward according to the methodology described in Chapter 2. Data source base map: TMG (2016).

Urbanization has typically been used as a growth strategy for cities (UN, 2015). Exploring urban concepts with green infrastructure can contribute to the development of new planning concepts that lead to sustainable stabilization and degrowth strategies (D'Alisa, Demaria, & Kallis, 2014). As shown in Figure 33, the areas with low population densities are the ones with the lowest self-sufficiency. Despite a rural to urban migration in Japan (The World Bank, 2016), the country is experience a general shrinkage in population and aging, which is predicted to influence urban areas (Faruqee & Mühleisen, 2003). However, there are currently no comprehensive degrowth strategies. Compact city development is a long-term endeavor, which includes expensive reforms in urban infrastructure (Neuman, 2005). Through the development of green infrastructure, this degrowth could in fact be utilized for the purpose of increase the quality and livability of urban areas as strategies for ecological urbanism (Mostafavi & Doherty, 2010).

4.1.2. Nutritional self-sufficiency across time in Nerima ward

The results of the nutritional self-sufficiency analysis showed that there is potential to utilize UA in disaster situations. However, these results remain low in comparison to the total population. The MHLW (2013) published a list of five important nutrients in disaster situations: energy [kcal], protein [g], vitamin B1 [mg], vitamin B2 [mg), and vitamin C [mg]. Vitamin C was found to be provided insufficiently in the emergency shelters of Iwate prefecture after the 2011 earthquake and Tsunami in Japan (Yokomichi et al., 2016) and was also shown in Chapter 3 as one of the main nutrients that is derived from fruits and vegetables in the Japanese diet. Because of the focus of MHLW on vitamin C and its importance in post-disaster situations, a further discussion is held on the contribution according to several scenarios as shown in Table 13.

The scenarios are designed as follows: S1 is described as the baseline self-sufficiency scenario of vitamin C in which the entire ward's population's self-sufficiency is assessed. S2 focuses on vulnerable populations of the ward (because of the lack of data only vulnerable age groups could be selected 0-14 and 60+ years old). S3 is designed according to the same ratio simulating a 7.3 magnitude earthquake under Tokyo Bay North Area (worst case scenario) that would force 3,390,000 evacuees (26% of population) of Tokyo to evacuate. Applying the simulation on Nerima ward on top of S2 shows that there is an increased potential to provide vitamin C to vulnerable populations that need to evacuate. Lastly, in S4 the potential provisioning from vacant lands (Appendix D1) is discussed for utilization in post-disaster situations. As was shown in Chapter 3, the self-sufficiency varies according to the time of year. Therefore, the scenarios were plotted accordingly as shown in Figure 34. It is shown that especially in summer and winter, the self-sufficiency of vulnerable age groups that require evacuation, with the utilization of vacant lands a self-sufficiency rate that exceeds 100% self-sufficiency eight time periods (81 days) in a year.

Table 13. Annual mean self-sufficiency of vitamin C by scenario in Nerima ward (2015)

Code	Description	Target group [people]	Mean vitamin C self-sufficiency [%]
S1	**Baseline** (entire population)	716,895	5.50
S2	**Vulnerable age groups** (0-14 and 60+ years old)	370,929	11.32
S3	**Evacuees** (26% of population)	96,442	43.52
S4	**Stable vacant lands** Vacant lands [n] 1,387.00 Area [m2] 318,987.48	96,442	67.77

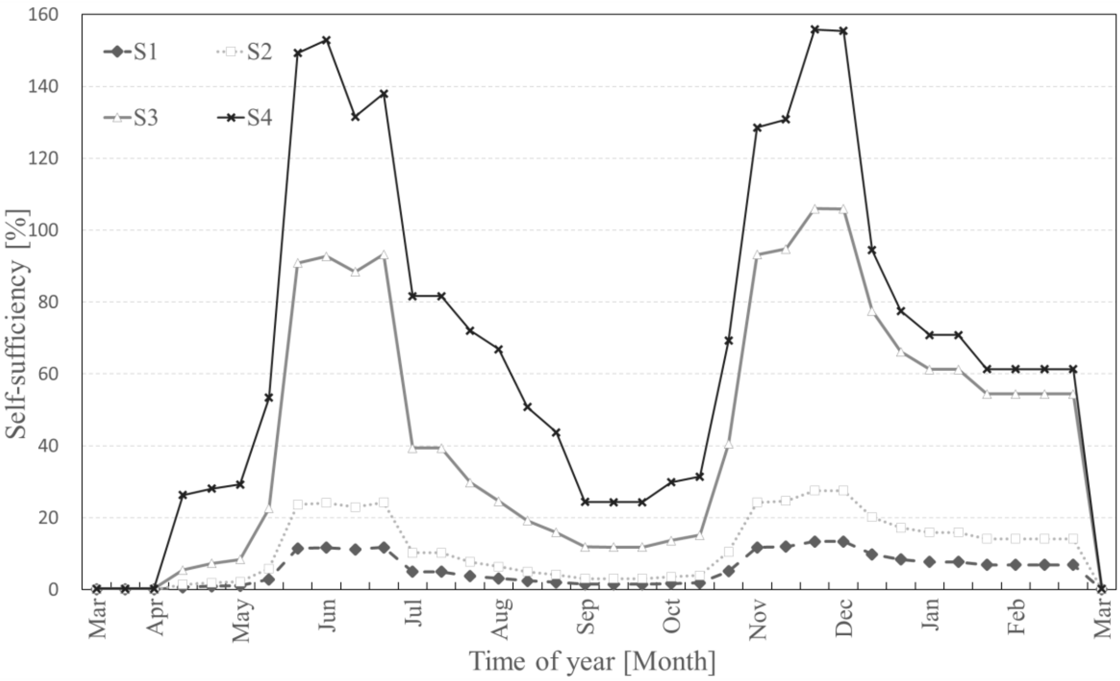


Figure 34. Self-sufficiency of vitamin C according to scenario in Nerima ward.

4.2. Practical considerations to utilize UA in post-disaster situations

4.2.1. Application

Regarding the year-round maintenance of UA activities, the hobby UA farmers can continue with their activities under the guidance of professional farmers. At present, more than 80% of hobby farmers engaged in experience UA must be from the local community (B. M. Shiraishi, 2001). However, there are some participants that commute from the urban core to an UA plot in a different area as well. In the case of an emergency situation, the stakeholder strategy in Nerima ward (Fig. 35) is adopted for the use on a neighborhood scale, because accessibility to other areas cannot be guaranteed.

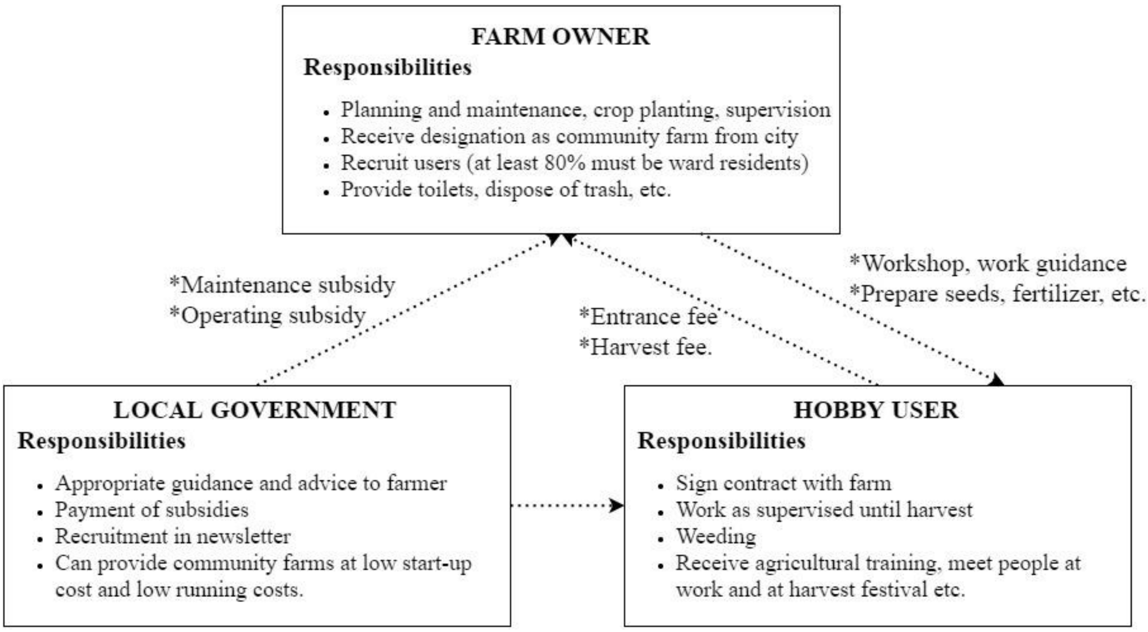


Figure 35. The Nerima Recreational Farm Initiative, and Merits to Participating Parties as described by The Central Union of Agricultural Co-operatives of Japan. Adopted and modified from Shiraishi (2001).

The example of Nerima ward's disaster drill described in Chapter 3 is brought forward as ideal case scenario. The farmer was a long-term professional farmer that next to his farming activity, was also appointed a role as community leader. This means that more people in the community can familiarize with the farmer and learn about the products and services (Open space, water for cooking, gas stove, toilets, emergency food, fresh agricultural produce) he can offer in case of a disaster. The described farm is also an experience farm, which ensures higher crop yields compared to the yields from other UA types (Tahara et al., 2011). In addition, the roles laid out in Figure 35 can be continued during emergency situations where the hierarchical structure can create order and efficiency. Because the market system is disrupted in an emergency situation, farmers should not charge the survivors and can be compensated from the local government after the emergency situation. The farmer, who functions as the key agricultural expert, continues to advice and delegate hobby farmers that can help facility the distribution of emergency supplies. This collective system allows for a deeper participation between local governments, land owners, and neighboring residents, which can lead to DRR improvements through the Yonmenkaigi system (Na, Okada, & Fang, 2009).

Nerima ward has already been promoting events to be held on agricultural lands for disaster preparedness. The Japan Agricultural Cooperative has been involved in activities such as the radish pulling event described in Chapter 1 for means of Promoting Agricultural Tourism and Interaction (Nerima ward, 2010).

4.2.2. Social cost

There is a very low social cost to the implementation of this study from urban planning perspective because of two main reasons. Firstly, there is a pre-existing important presence of UA in Tokyo (as shown in Chapter 2, and discussed by the intended utilization of UA in Nerima ward for disaster situations, which indicates the interest of the ward government), and secondly, unutilized stable vacant lands can be gradually transformed into allotment farms. This transformation can occur according to the rise in demand from urbanites. Allotment farming is the ideal farming type to apply because they are applicable on any plot shape or size (Mougeot, 2000), without requiring land readjustment (Sorensen, 2000). This follows the concept of EBDRR, which has proven to be a cost-effective method for mitigating the impacts caused by natural disasters and presenting effective strategies for increasing resilience through the provision of food, water, and building materials (Sudmeier-Rieux & Ash, 2009; UNEP & CNRD, 2014), rather than through changes in the hard infrastructure such as widening roads and providing additional evacuation spaces. Furthermore, in Japan, there is still a high demand for UA by especially retirees as "Grow your own food" has become a popular hobby, which can help achieve successful aging (Rowe & Kahn, 1987, 1997), as well as with an increasing number of young families valuing UA as an educational platform for their children, causing long waiting lists in allotment and experience farms.

Similarly, the social cost remains low in the case of Japan because of the preparedness of the population. Cavallo, Cavallo, & Rigobon (2014) found that in a post-disaster comparative study between Chile and Japan, in both cases product availability recovered slowly, and a significant share of goods remained out of stock after six months. In the context of Chile, out of fear of "Consumer anger" prices were affected with frequent changes, while in Japan changes remained relatively stable, even for goods that were lacking in the areas. This was especially the case for non-perishable goods and emergency products. This comparison study shows that the application of UA to provide dietary nutrition in different cultural settings than Japan may have to deal with more complex social issues.

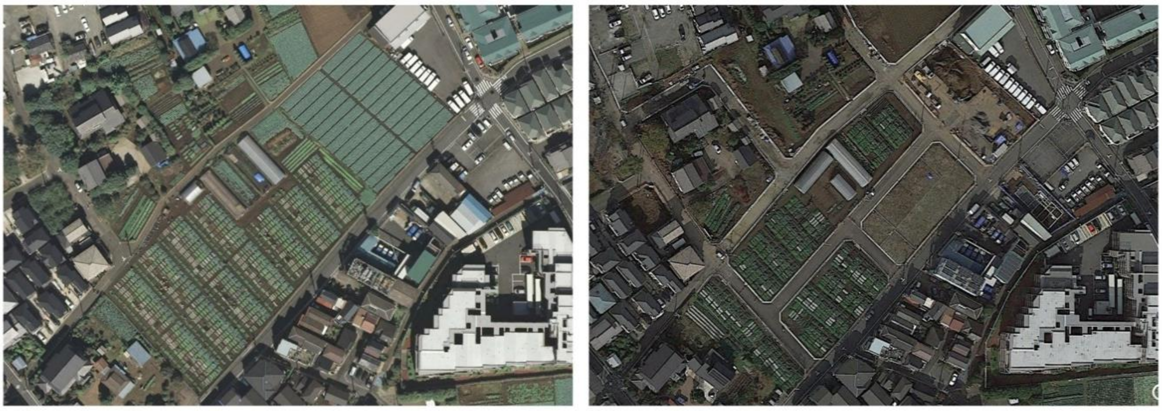
The social cost in terms of UA as disaster preparedness food is also very low. One household study in Japan showed that revealed that most households did not store rations or did so insufficiently (e.g. only beverages) (Nakazawa & Beppu, 2012). Local government's already stock dietary supplements for several days, however, previous post-disaster studies showed that these are not always prepared timely after disasters, especially when different disasters occur in a short time span (Amagai et al., 2014). There have been cases when the supplement provider was damaged, causing a shortage in dietary supplements (Inoue et al., 2014). Also, in the case of disasters, heavily damaged areas with narrow roads might not be accessible over long periods of time, requiring resources from within the area. Having a constant supply and use of existing UA as shown in summer, fall, and winter seasons in Chapter 3 can help diversify the sources of dietary nutrition for emergency situations without relying on external sources.

4.3. Policy implications

Three main policy implications can be suggested from the results in the present case study. These implications are derived from concerns raised in Chapter 1 (existing policies), Chapter 2 (utilization of unutilized land uses), and Chapter 3 (utilization of UA in disaster situations) as follows:

The first relates to The Productive Green Land Act enacted in 1974 and revised in 1992 as introduced in Chapter 1. This land is located in Urbanization Promotion Area (UPA) under the City Planning Act (1968) (Okata & Murayama, 2011). UPA is the zoning area that was intended for development within a 10 year period. UPA was taxed as urban land; however, in reality, many agricultural land uses were not transformed into urban land uses and were too expensive to maintain under such an expensive taxation system. The Productive Green Land Act lowered the taxation for farmers willing to commit the land for the next 30-year to agricultural purposes. However, restrictions such as the size of the land, for the farmland to be illegible as productive green, are in place. In 2022, farm owners under this Act will have fulfilled their commitment and are allowed to transform their lands into other land uses if desired. The present thesis highlighted the importance of UA in the megacity context of Tokyo (e.g. exposure to large earthquakes) and suggests that further commitment is to be made for the protection of UA in dense urban areas. Previous design interventions as discussed in Chapter 2 and suggested by Viljoen & Howe (2012) showed the possibility to transform urban land uses for agricultural purposes even in compact cities. To reduce the opportunity cost, new tax reductions can be applied if further commitment is made to agricultural land use. Simultaneously, land owners that decide to change to an urban land use (e.g. residential land use), should bear the costs of land readjustment in anticipation of further development and ensure sufficient open space for the community to evacuate while ensuring a visually green character of the community (Yagasaki &

Nakamura, 2008a). An example of land readjustment and its influence on productive green is shown in Fig. 36.



a) b)

Figure 36. (**a**) Satellite imagery (1997) of an experience farm in Nerima ward; (**b**) Satellite imagery (2015) when land readjustment took place. Source: Google Earth image a) Oct. 2nd, 1997; image b) Nov. 29th, 2015. Accessed March 30th, 2017.

The second policy implication relates to the transformation of underutilized urban land uses to UA productive purposes (Appendix A5 as addressed in Chapter 2). Tokyo contains a vast number of small-scale vacant lots. Most plots are too small (average size = 840 m^2, median = 153 m^2 (TMG, 2016)) for professional UA. These lands can currently not be recognized by the productive green land act due to restrictions in the minimum sizes. Some lands are underutilized over long periods of time, particularly in areas with high population densities and limited amount of additional open spaces. Transformation of these stable vacant lots into Hobby UA can increase resilience by providing populations residing in these areas with evacuation spaces and a fresh supply of nutrients when a natural disaster occurs while providing environmental and economic services (Debolini et al., 2015).

The third policy implication relates to The Disaster Prevention Cooperation Farmlands as introduced in Chapter 3. Farmers can voluntarily register their farmlands as evacuation space and for building temporary shelters during emergencies. However, currently no means exist for the utilization of available crops on the land and continued agricultural activity. Through the results of the present study, it was found that these UA lands contain valuable nutrient for affected survivors. Therefore, it is proposed to allow the harvest during emergencies as described in the application Chapter 4.1. In summary, the stakeholders remain the key facilitators in the distribution of the harvest during emergencies, insuring an organized and equal distribution.

4.4. Practical recommendations

Based on the discussions in Chapters 2 and 3, as well as the integrated discussion in Chapter 4 a list of eight practical recommendations were developed that governments can adapt in their strategies and urban planners can strengthen in their designs. Adapting these recommendations can address the literature gaps described in Chapter 1 as follows:

1) analyze self-sufficiency levels for different land use patterns across the city region to target policy interventions according to type of land use pattern and eliminate the threats to resilience (Chapter 2);

2) increase the mixture of land uses that are related to increasing the resilience of the population in high density areas (Chapter 2);

3) on the international scale, adjust interventions with emergency food based on the time of year the disaster takes place to avoid dietary related health issues among survivors (Chapter 3);

4) on a regional scale, develop community events that link education and lifestyle with disaster awareness that can foster participation in agricultural activities (Chapter 3);

5) on the local scale, move from an emergency response to an emergency preparedness approach by ensuring sufficient and diverse food sources (Chapters 2 and 3);

6) ensure the provisioning of “live rations” which can be harvested on day-to-day basis as well as during emergency events to diminish the reliance on emergency supplies (Chapter 3);

7) develop strategic interventions in high risk urban areas (e.g. areas with high populations, narrow roads, and limited open space) to increase productive open green spaces (Chapter 4);

8) foster strong partnerships across governmental agencies, private companies, community groups, and non-profit organizations to better streamline resources in times of emergencies (Chapter 4).

The implementation of urban planning interventions is a complex matter and may take time (Sioen et al., 2016b). To avoid failure and resistance of key actors, participation of local actors is required to successfully adjust and adopt such policies on different scales. Therefore it is recommended to engage in discussions and listen to the needs of local governments, professional farmers, hobby farmers, and neighboring residents of each area (e.g. municipality) throughout the decision making process (e.g. with the help of the well-established Yonmenkaigi system (Na et al., 2009)). Despite the good intentions to provide sufficient fruit and vegetables containing valuable nutrients to the populations, each land owner should have an independent organization conduct a soil and water quality analysis to avoid other unforeseen health impacts and contaminated lands should not be utilized for agricultural production (Nassauer & Raskin, 2014). Lastly, the promotion of UA activities in the cities should consider the aging society of UA farmers leading to a democratization of UA. Promoting the hobby UA activities can lead to improvements of underutilized lands (as allotments UA can be organized on any shape or size of land) and experience UA can improve the total harvest of fruits and vegetables of urban communities by utilizing the larger vacant lands (Appendix A4) with its efficient yields compared to other UA types as discussed in Chapter 2.

5. CONCLUSION

This thesis addresses the aforementioned gaps in existing literature and concluded that urban-rural mixed land uses in cities contribute to disaster preparedness and resilience of urban populations. Depending on the time of year, urban agriculture provides a considerable amount of vegetables containing valuable nutrients in post-disaster situations for the prevention of health issues reported in post-disaster studies.

A description of the reasons for the substantial presence of agricultural land uses in Japanese urban areas in contrast to that in European and American cities (Chapter 1) is made. Also, the importance of different UA land uses in a megacity context to improve disaster preparedness (Chapter 2) was made. This is achieved with a spatial analysis of the Tokyo city region (Tokyo 23 wards and the Tama area, excluding the islands) to analyze the gradient from urban core to forestry/natural area and its corresponding self-sufficiency rates. Furthermore, the benefits of UA that can help to avoid dietary related health issues in the aftermath of a large disaster (Chapter 3) was discussed for the case study of Nerima ward. Moreover, an integrated discussion was held on the role of UA in cities around the world through the present case study and what active steps can be taken to protect UA from more economically profitable land uses (Chapter 4). Finally, practical recommendations were developed for the city region of the present case study and cities around the world with similar land uses (Chapter 5).

The following paragraphs summarize and conclude the content of each chapter in this thesis: Chapter 1: It was highlighted that distinct types of agriculture can be found in Japanese cities because of their historical, and geographical contexts. Farms in Japan remain dependent on expensive, manual labor because they tend to be small and cannot easily mechanize their production process. Farmlands in Japanese cities also go beyond mere food production. Firstly, they contribute to the resilience of the city by providing evacuation spaces and diverse food supply in case of disaster. Secondly, as a super-aging society with most residents living in urban and urban fringe areas, there is a potential for farmlands to function as a social platform. Inviting neighboring aged residents and young families, to cultivate and maintain the farmland could address some of the social and demographic issues. Some farm households and entrepreneurial businesses have begun to experiment with such approaches, making skill transfer a greater source of income than crop production. To avoid further land abandonment, which consequentially leads to the loss of context-specific ecosystem services and resilience to natural disasters, the agricultural sector should invite newcomers to cultivate the lands. It was also highlighted that Tokyo has the highest exposure rate to large earthquakes.

Chapter 2: An analysis identifying UA alongside their locations and characteristics was conducted. Utilizing this primary data, it was shown that Tokyo contains a variety of land use patterns that corresponds with the gradient from urban core to forest or natural area. There was found to be a total fruit and vegetable self-sufficiency of 4.22% in urban areas. Especially the two patterns defined in between as urban with open spaces and urban with agriculture land uses showed the highest potential in fruits and vegetable self-sufficiency as well as in the self-sufficiency of selected nutrients in correspondence to its high population density. Furthermore, an in-depth analysis on the types of UA practices in Tokyo showed linkages between the land use patterns and self-sufficiency rates. In addition, it was highlighted that areas with a variety of UA practices had positive influences on the availability of selected dietary nutrients. In addition, the transformation of stable vacant lands to UA land uses could contribute substantially to the self-sufficiency of each community.

Chapter 3: It was shown that UA has potential to supplement rations and other emergency foods as disaster preparedness food, depending on the time of year, during post-disaster situations. If contemporary emergency food rations is to prevent diet-caused symptoms among survivors, such rations should be better strategized with local UA availability and the time of year the disaster takes place. Further discussion showed that with a focus on vulnerable groups and evacuees the contribution from UA becomes even more valuable. This chapter has implications for policies and emergency response strategies around the world – especially in countries with limited infrastructural investments - to increase the intake of vegetables with crucial nutrients from UA during post-disaster situations.

Chapter 4: It was discussed that UA farmers can continue their regular roles in the community and farming activities in case of an emergency event. Majority of hobby farmers come from the local community, which means that they can access nutrients from UA within close proximity to their residences. The stakeholder strategy for experience farms from Nerima ward was adapted and modified for the roles of the local government, professional farmer, and hobby farmers during emergency events. Furthermore, three main policy implications were suggested: 1) continuation of the Green Land Act beyond the 30 year restriction and reduction of the restrictions in sizes; 2) transformation of underutilized urban land uses as described in Chapter 2 since they can contribute a substantial amount of land for UA production and lead to increased self-sufficiency in low self-sufficiency areas; 3) improvements to The Disaster Prevention Cooperation Farmlands system, which currently does not allow harvest of the agricultural products. Finally, a list of eight practical recommendations was developed with applicability on different scales to increase the resilience of cities based on the discussions and findings of each chapter in Chapter 5.

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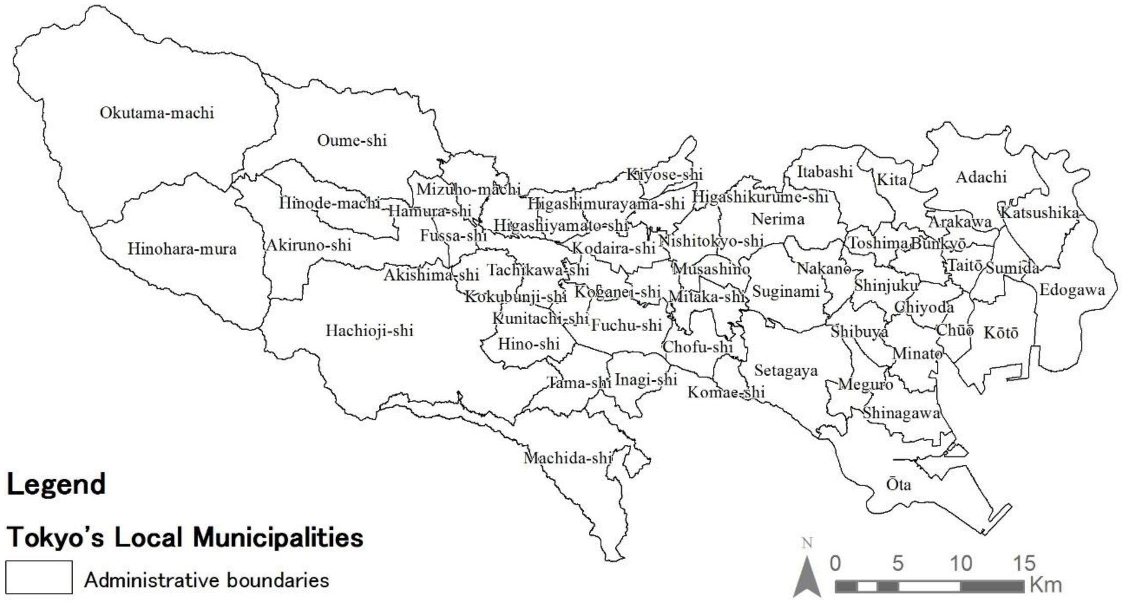
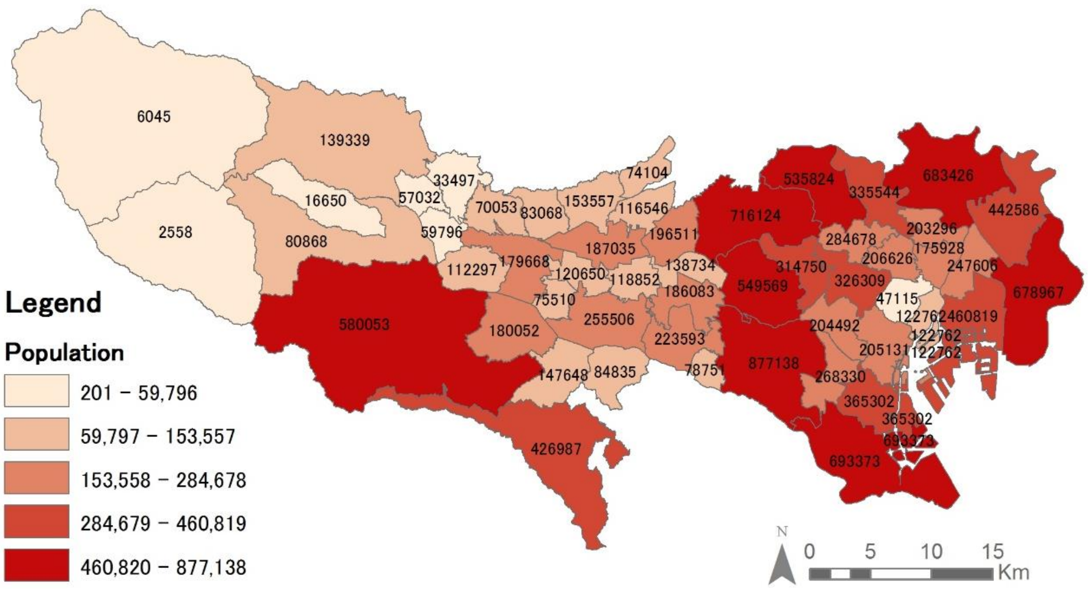
7. APPENDICES

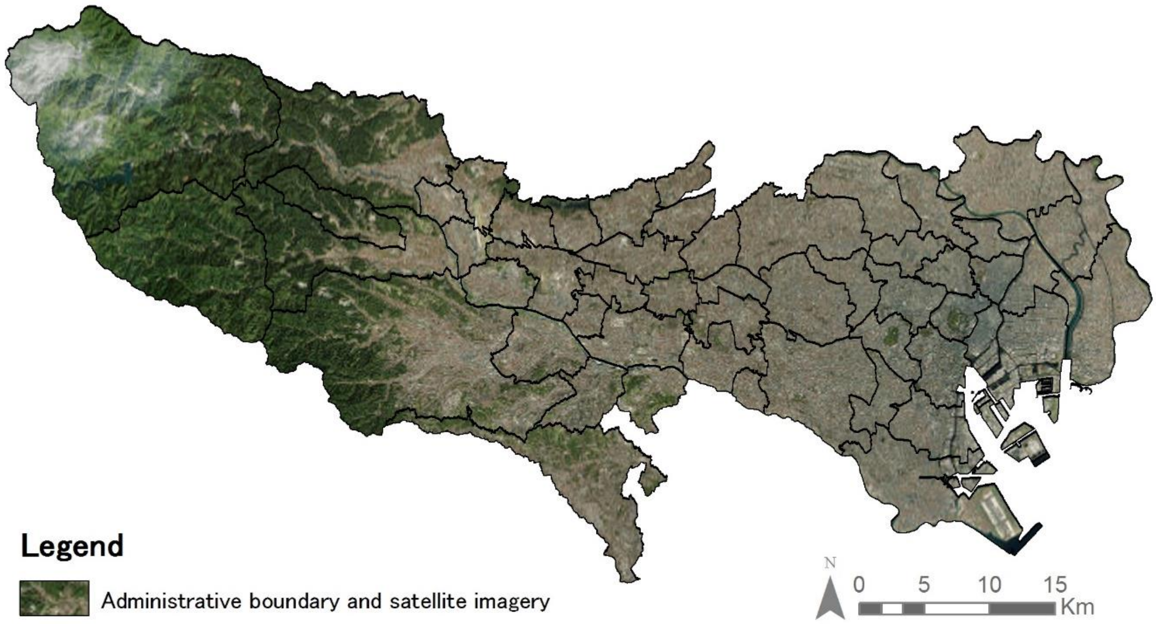
Appendix A: General maps and results of the Tokyo case study



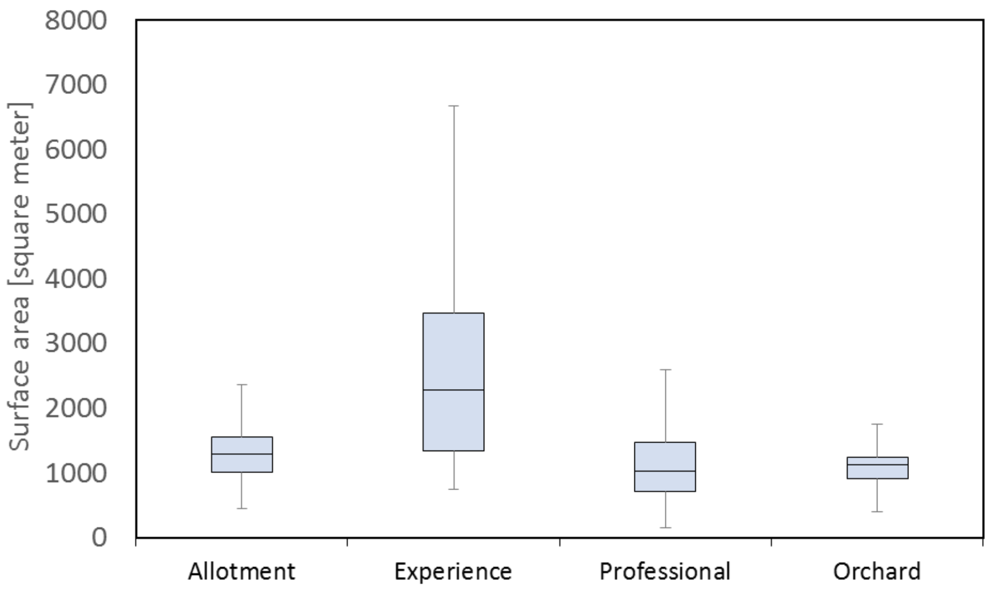
Appendix A1. Map of Tokyo metropolis and names for each municipality. Data source base map: Administrative map of Tokyo's municipalities and land use data (TMG, 2016).



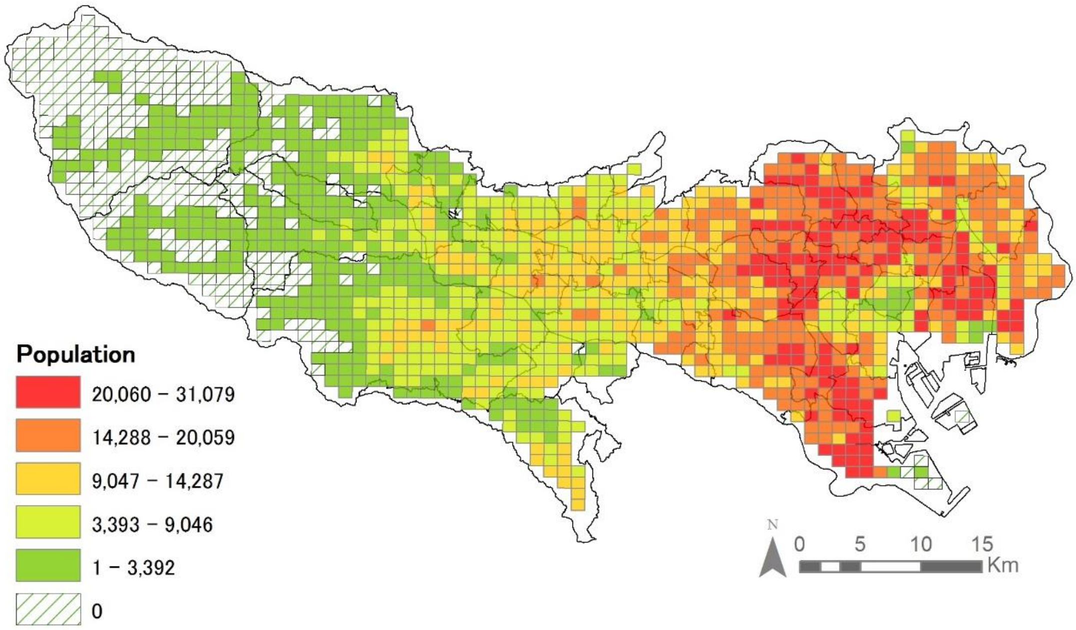
Appendix A2. Map of Tokyo metropolis with the population of each municipality. Data source base map: Administrative map of Tokyo's municipalities and land use data (TMG, 2016).



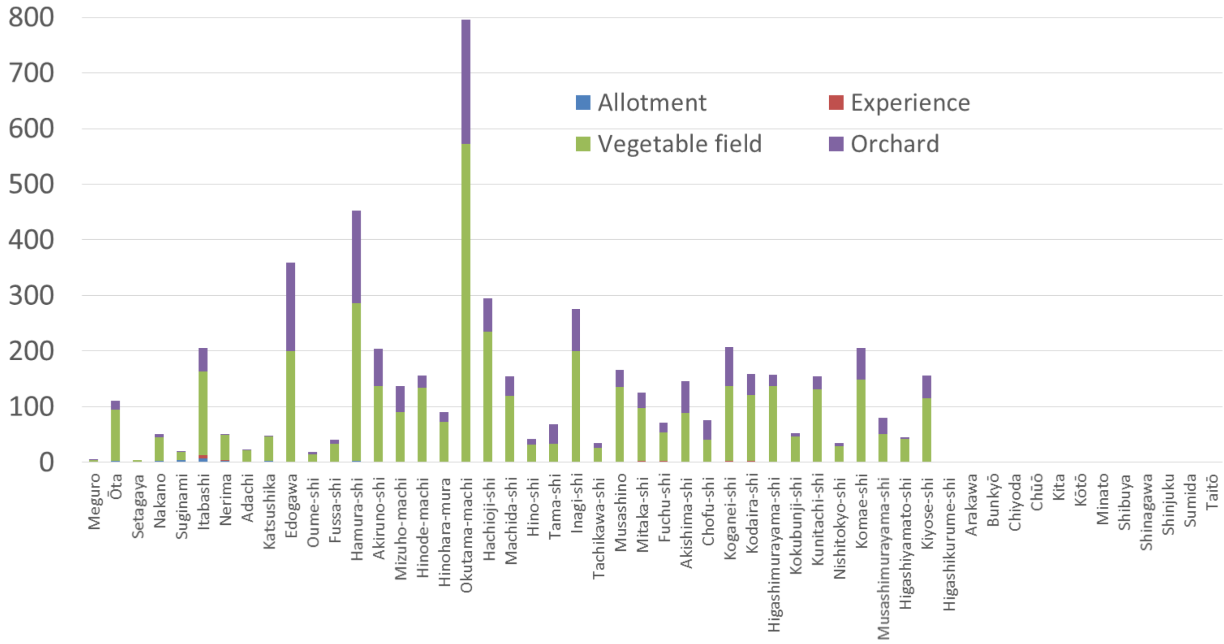
Appendix A3. Map of Tokyo metropolis with the population of each municipality. Data source base map: Administrative map of Tokyo's municipalities and land use data (TMG, 2016).



Appendix A4. Box plot indicating the median surface area of each type of farmland in Tokyo, Japan.



Appendix A5. Map with population within each 1 km^2 grid cell of Tokyo. Data source base map: Administrative map of Tokyo's municipalities and land use data (TMG, 2016).



Appendix A6. Figure indicating the aggregated production [kg] by municipality for each UA type. Data derived from (TMG, 2015b).

Appendix B: Summary of results by municipality

Appendix B1: Results used for calculation, general and professional UA (vegetables and orchards).

Municipality	Grid cells [n]	Popul-ation [n]	Veg. [n]	Veg. [m^2]	Veg. [kg/m^2]	Orch. [n]	Orch. [m^2]	Orch. [kg/m^2]
Adachi-ku	43	598,183	692	509,199	2.50	17	15,576	0.19
Akiruno-shi	67	75,815	2,329	2,754,156	1.27	1,398	1,560,642	0.08
Akishima-shi	16	112,755	548	521,723	1.27	174	164,928	0.59
Chofu-shi	16	182,738	790	871,729	2.37	511	595,469	0.16
Edogawa-ku	33	535,834	552	441,955	7.24	10	10,139	0.10
Fuchu-shi	31	267,215	1,341	1,195,962	1.33	376	322,094	0.38
Fussa-shi	10	51,966	277	319,441	0.97	92	77,488	0.00
Hachioji-shi	169	576,413	5,193	5,763,241	1.44	2,150	2,300,702	0.09
Hamura-shi	9	58,191	445	306,567	1.86	107	68,293	0.16
Higashikurume-shi	9	82,987	603	1,029,594	2.38	324	371,247	0.35
Higashimurayama-shi	14	136,488	663	1,210,846	1.70	270	399,229	0.91
Higashiyamato-shi	10	77,608	565	468,245	1.73	328	294,252	0.30
Hinode-machi	26	16,731	924	940,845	0.90	489	518,103	0.08
Hinohara-mura	87	2,523	616	1,338,408	0.36	242	221,672	0.01
Hino-shi	26	185,258	1,755	1,138,494	1.79	472	339,463	0.90
Inagi-shi	10	49,676	616	361,237	2.86	314	339,140	3.24
Itabashi-ku	24	482,300	232	152,904	1.32	17	16,313	0.52
Katsushika-ku	25	375,617	254	149,887	6.43	2	768	1.23
Kiyose-shi	3	27,006	174	433,286	8.92	48	36,768	1.67
Kodaira-shi	18	167,597	888	1,373,282	1.91	559	679,021	0.47
Koganei-shi	10	119,714	385	352,097	1.57	286	333,699	0.14
Kokubunji-shi	12	138,673	642	1,072,857	1.27	213	253,938	0.38
Komae-shi	5	71,800	259	278,185	2.08	61	52,719	0.42
Kunitachi-shi	6	60,274	350	341,362	1.30	56	47,273	0.27
Machida-shi	38	207,577	1,717	2,285,999	2.36	503	578,804	0.40
Meguro-ku	14	269,868	33	28,292	1.98	3	5,171	0.54
Mitaka-shi	16	184,287	738	1,214,422	1.42	195	249,419	0.60
Mizuho-machi	11	25,972	853	1,489,260	0.91	600	713,656	0.03
Musashimurayama-shi	15	75,694	1,159	1,508,118	1.38	538	584,291	0.11
Musashino-shi	9	129,461	174	290,871	2.17	34	44,792	0.56

Nakano-ku	15	317,483	56	42,606	1.46	0	0	0.00
Nerima-ku	43	671,551	1,394	1,687,734	3.18	441	512,204	0.40
Nishitokyo-shi	12	156,136	512	1,110,181	1.85	167	200,072	0.50
Okutama-machi	194	6,113	741	740,530	0.70	204	192,302	0.08
Ota-ku	31	503,925	62	33,019	0.78	9	5,604	0.18
Ome-shi	91	143,323	3,042	2,045,859	1.96	2,052	1,568,020	0.10
Setagaya-ku	51	837,680	917	961,678	0.81	149	189,519	0.20
Suginami-ku	31	520,674	351	397,956	1.40	53	82,115	0.36
Tachikawa-shi	24	178,962	1,214	2,029,805	1.27	549	739,220	0.17
Tama-shi	21	151,136	512	402,858	1.29	149	117,751	0.33
Arakawa-ku*	8	170,193	2	647	2.04	0	0	0.43
Bunkyo-ku*	10	184,941	1	244	2.04	0	0	0.43
Chiyoda-ku*	12	58,291	0	0	2.04	0	0	0.43
Chuo-ku*	6	86,955	0	0	2.04	0	0	0.43
Kita-ku*	19	350,817	14	5,645	2.04	2	1,055	0.43
Koto-ku*	25	402,399	4	824	2.04	0	0	0.43
Minato-ku*	16	164,200	0	0	2.04	0	0	0.43
Shibuya-ku*	15	225,441	3	444	2.04	0	0	0.43
Shinagawa-ku*	17	358,192	3	587	2.04	2	1,110	0.43
Shinjuku-ku*	18	326,027	5	1,122	2.04	0	0	0.43
Sumida-ku*	15	283,934	2	416	2.04	0	0	0.43
Taito-ku*	10	182,861	0	0	2.04	0	0	0.43
Toshima-ku*	13	284,945	5	1,073	2.04	0	0	0.43
Total	1,479	11,912,400	34,607	39,605,687	108	14,166	14,804,042	23

Veg. = Vegetable; Orch. = Orchards.

Appendix B2: Hobby UA (Allotment and experience).

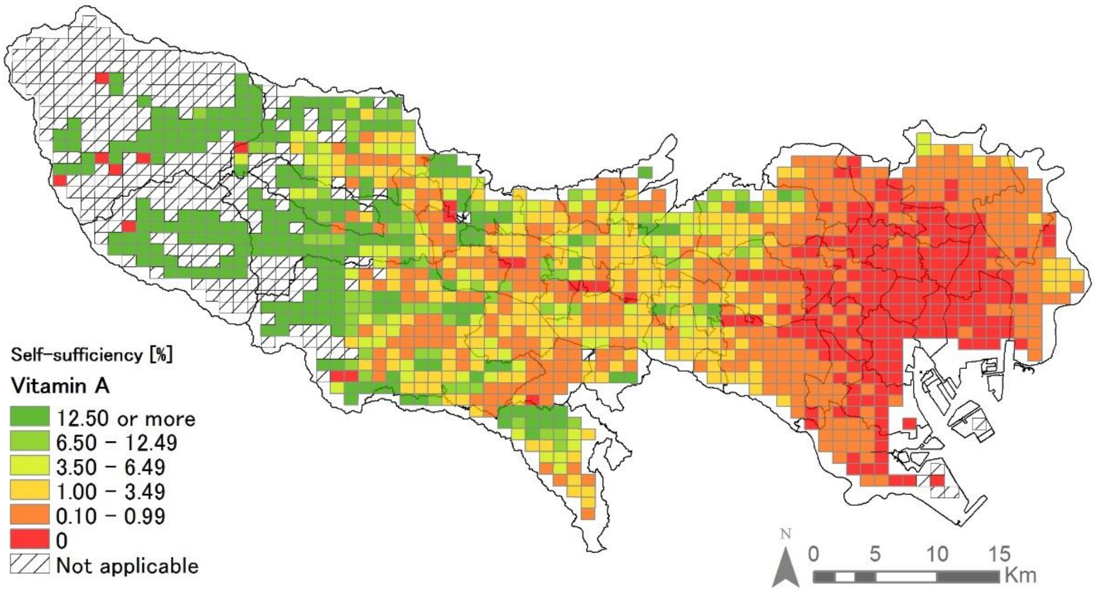
Municipality	All. [n]	All. [m^2]	Exp plots [n]	Exp [m^2]	Vacant [n]	Vacant [m^2]
Adachi-ku	15	30,200	4	5,546	1,180	714,707
Akiruno-shi	22	30,547	0	0	1,266	880,883
Akishima-shi	17	17,412	2	6,454	573	906,820
Chofu-shi	5	7,808	0	0	311	106,274
Edogawa-ku	24	25,145	2	1,486	748	251,784
Fuchu-shi	25	23,558	7	11,648	785	597,953
Fussa-shi	0	0	0	0	157	60,248
Hachioji-shi	7	5,663	0	0	3,906	4,936,624
Hamura-shi	4	3,585	1	3,649	220	106,259
Higashikurume-shi	5	4,898	0	0	195	63,815

Higashimurayama-shi	5	13,892	7	16,116	358	147,834
Higashiyamato-shi	8	15,418	1	2,181	344	160,622
Hinode-machi	4	4,552	0	0	303	461,296
Hinohara-mura	0	0	0	0	76	56,376
Hino-shi	13	16,608	0	0	1,007	719,344
Inagi-shi	0	0	1	612	440	520,188
Itabashi-ku	49	40,602	0	0	616	213,598
Katsushika-ku	15	18,125	0	0	707	293,158
Kiyose-shi	2	4,913	0	0	50	33,349
Kodaira-shi	7	9,135	4	10,250	376	146,417
Koganei-shi	10	8,529	2	3,657	140	38,726
Kokubunji-shi	8	14,443	1	1,825	238	135,260
Komae-shi	9	7,556	0	0	88	25,615
Kunitachi-shi	10	14,743	0	0	115	68,269
Machida-shi	2	1,322	0	0	1,095	1,609,565
Meguro-ku	0	0	0	0	489	135,512
Mitaka-shi	6	5,178	1	863	279	87,911
Mizuho-machi	0	0	0	0	351	250,417
Musashimurayama-shi	7	4,259	0	0	345	2,687,486
Musashino-shi	7	9,988	0	0	126	40,525
Nakano-ku	0	0	1	2,232	847	232,646
Nerima-ku	56	77,799	23	70,742	1,406	328,254
Nishitokyo-shi	7	8,396	4	7,452	278	87,838
Okutama-machi	0	0	0	0	227	108,104
Ota-ku	5	5,627	0	0	762	264,470
Ome-shi	18	20,242	0	0	1,027	698,445
Setagaya-ku	23	23,954	7	6,094	1,187	319,700
Suginami-ku	10	15,827	0	0	764	253,506
Tachikawa-shi	1	651	7	11,208	628	1,560,637
Tama-shi	7	8,234	0	0	580	681,737
Arakawa-ku*	0	0	0	0	297	74,292
Bunkyo-ku*	0	0	0	0	181	71,603
Chiyoda-ku*	0	0	0	0	136	47,285
Chuo-ku*	0	0	0	0	192	43,194
Kita-ku*	0	0	0	0	453	168,915
Koto-ku*	1	2,895	0	0	516	493,155
Minato-ku*	16	164,200	0	0	2.04	0
Shibuya-ku*	15	225,441	3	444	2.04	0

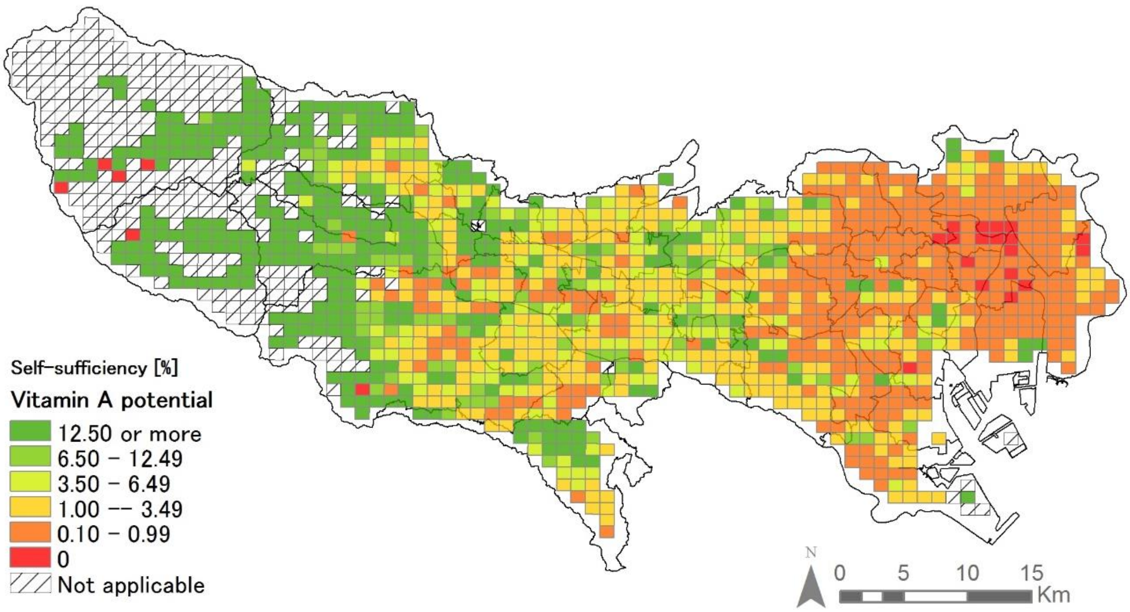
Shinagawa-ku*	17	358,192	3	587	2.04	2
Shinjuku-ku*	18	326,027	5	1,122	2.04	0
Sumida-ku*	15	283,934	2	416	2.04	0
Taito-ku*	10	182,861	0	0	2.04	0
Toshima-ku*	13	284,945	5	1,073	2.04	0
Total	1,479	11,912,400	34,607	39,605,687	108	14,166

All. = Allotment; Exp. = Experience.

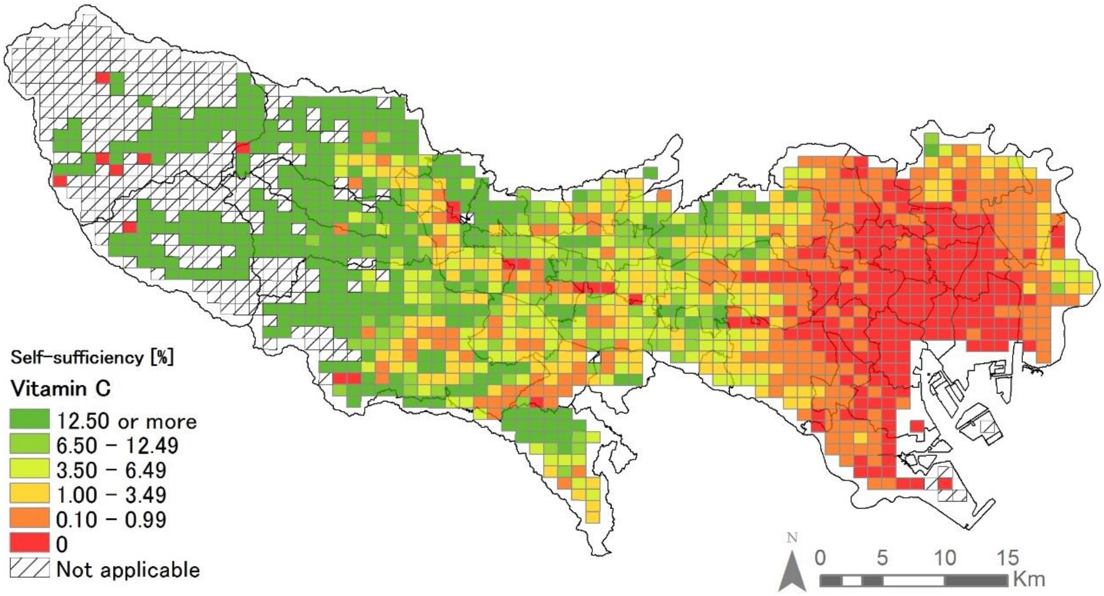
Appendix C: Maps of the nutritional self-sufficiency of the Tokyo case study



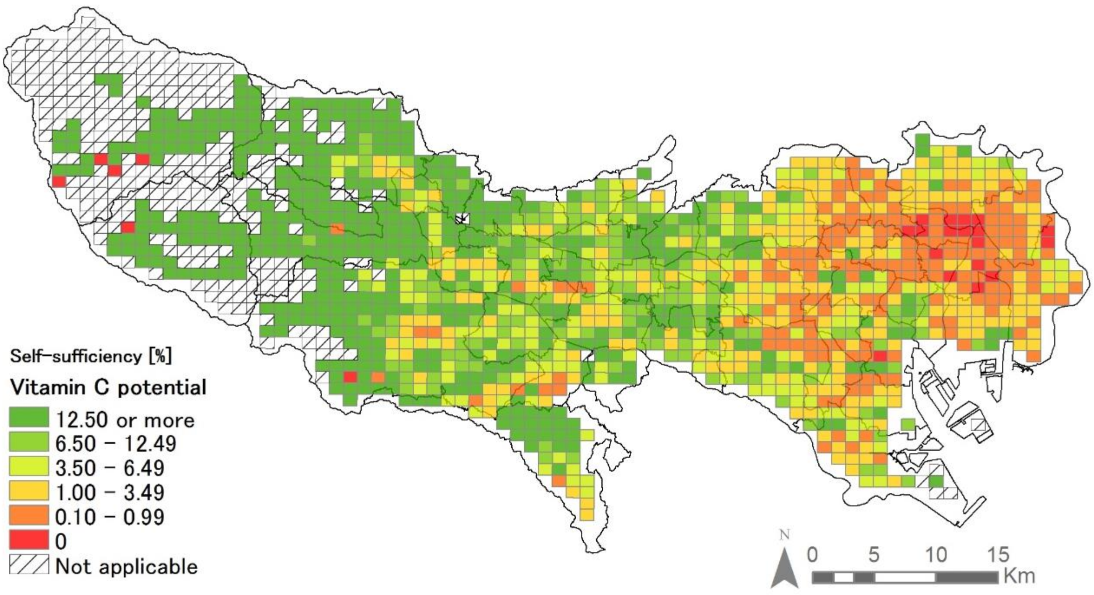
Appendix C1. Current vitamin A self-sufficiency within each 1 km^2 grid cell of Tokyo. Data source base map: Administrative map of Tokyo's municipalities and land use data (TMG, 2016).



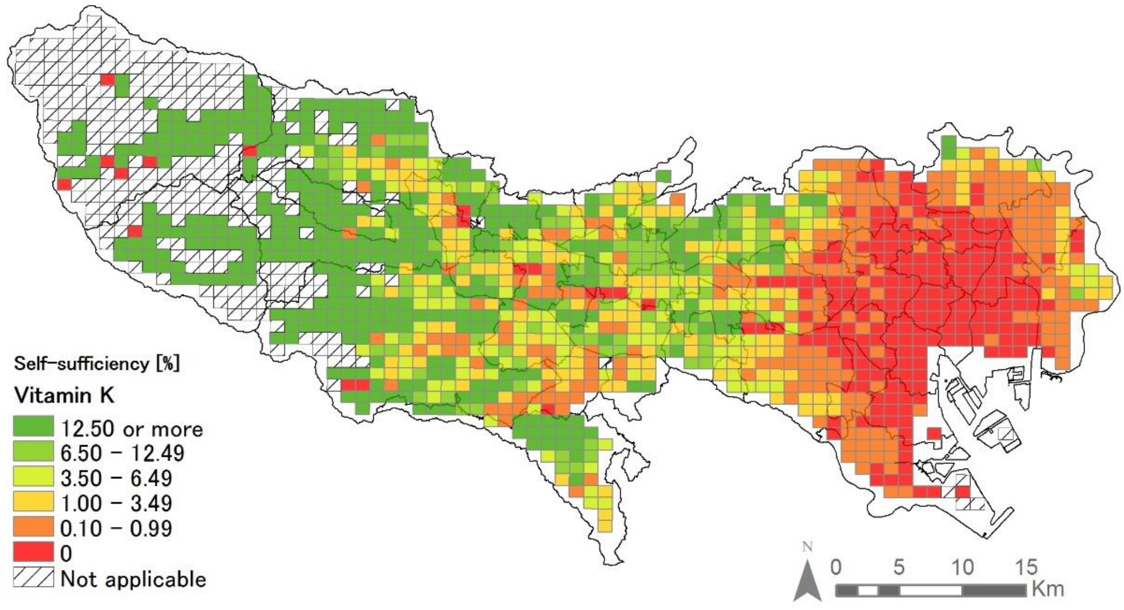
Appendix C2. Potential vitamin A self-sufficiency within each 1 km^2 grid cell of Tokyo. Data source base map: Administrative map of Tokyo's municipalities and land use data (TMG, 2016).



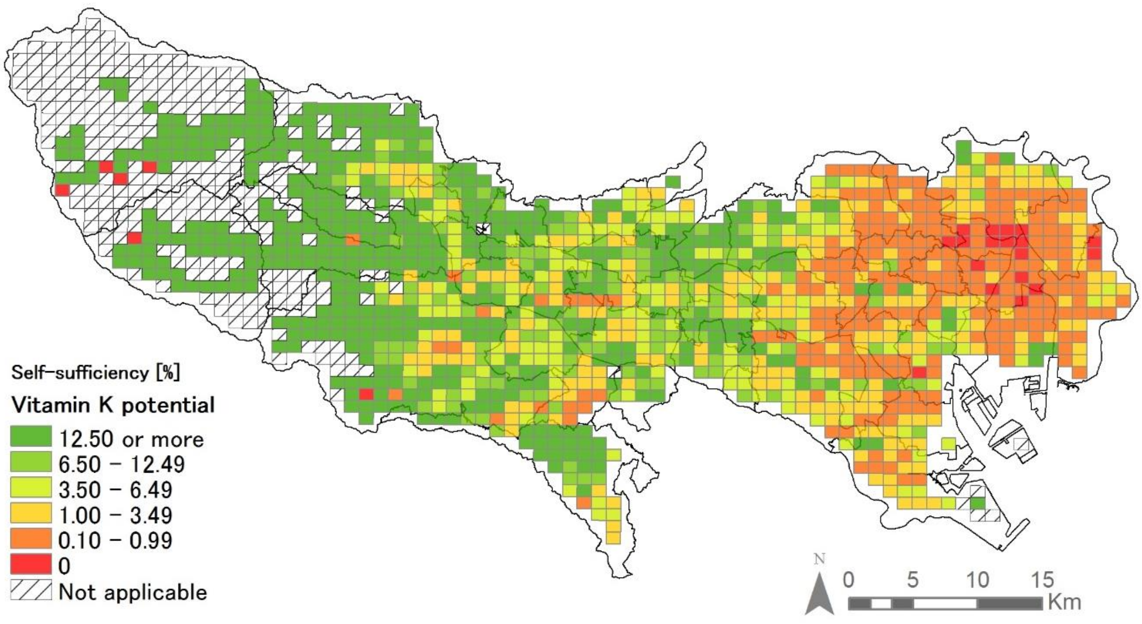
Appendix C3. Current vitamin C self-sufficiency within each 1 km^2 grid cell of Tokyo. Data source base map: Administrative map of Tokyo's municipalities and land use data (TMG, 2016).



Appendix C4. Potential vitamin C self-sufficiency within each 1 km^2 grid cell of Tokyo. Data source base map: Administrative map of Tokyo's municipalities and land use data (TMG, 2016).

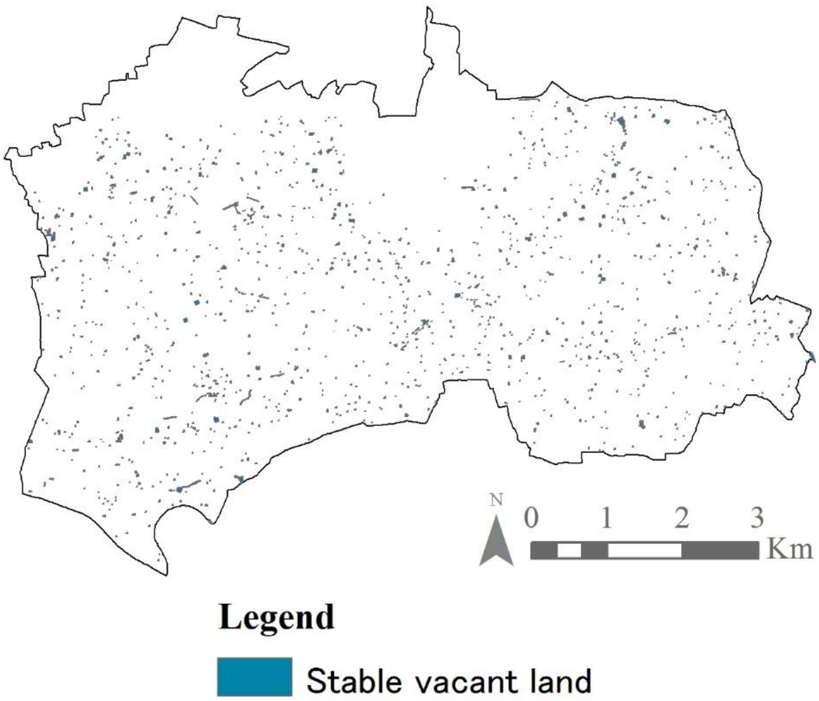


Appendix C5. Current vitamin K self-sufficiency within each 1 km^2 grid cell of Tokyo. Data source base map: Administrative map of Tokyo's municipalities and land use data (TMG, 2016).



Appendix C6. Potential vitamin K self-sufficiency within each 1 km^2 grid cell of Tokyo. Data source base map: Administrative map of Tokyo's municipalities and land use data (TMG, 2016).

Appendix D: Maps of the Nerima ward case study



Appendix D1. Stable vacant lands derived from Chapter 2 for Nerima ward. Data source base map: Administrative map of Tokyo’s municipalities and land use data (TMG, 2016).