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Developing Adaptation Strategy against Earthquake beneath Tokyo Metropolitan in a Context of Future Demographic Transition

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Synopsis

Demographic transition has been widely discussed but rarely examined in the disaster research context. This paper is aimed to simulate population exposure and disaster resilience for developing adaptation strategies against the Earthquake beneath Tokyo Metropolitan. Conducting mesh-based population estimation in cohort component analysis, we examine population exposure by transition in density, age and family structure. Based the empirical studies of the 1995 Kobe Earthquake and the 2004 Niigata Chuetsu Earthquake, this paper estimates disaster resilience transformation to visualize the impact of future demographic transition. Integrating seismicity, population exposure and disaster resilience, this paper suggest business continuity planning and community capability reinforcement as adaptation strategies.

Keywords: population decline, aging, resilience, Earthquake beneath Tokyo Metropolitan

1. Introduction

During the past decades, Japan has witnessed a remarkable demographic transition in population decline and population aging. Aged 65 and above population ratio reaches 7% (aging society) in 1970, and 14% in 1994 (aged society) in 1994, then 20% in 2005 which leads Japan become the oldest county in the world eventually (Fujita, 2007; United Nation, 2007). According to the National Institute of Population and Social Security Research (2006), the demographic transition tends to accelerate and reveals a completely different population structure against the current situation. It is noted that, the population in 2030 might remain 90% of the present population. Also, the aged 65 and plus population proportion might cross 30%. The prospective trend attracts great concentration from various fields.

Yet the Earthquake beneath Tokyo Metropolitan is expected to occur with 70% probability before 2030 (Central Disaster Prevention Council, 2005). It is believed that the probability is likely to increase gradually and become an inevitable issue for disaster management of Tokyo Metropolitan. Although, it is agreed that population growth or aging gives a positive effect to vulnerability (e.g. Mileti 1999; Cutter et al., 2003), future transition is not taken into account by pre-disaster planning for post-disaster recovery (Nakabayashi, 2004; Ichiko, 2006). Thus, this paper aims to evaluate impact of future demonstration transition, and to develop the adaptation strategy for reinforcing resilience, the ability to correspond to external, internal change and to adjust itself to cope with (Hayashi, 2009).

2. Research Approach

Many studies have integrated population census data and seismicity into casualty assessment. One direct approach is to collect population exposure in a spatial analysis by overlapping seismicity with population distribution (Nojima et al., 2006) or population census data (Suzuki & Hayashi, 2009). On the other hand, Chen et al. (2010a) intend to take demographic transition into account. By simulating population, it is assessable to analyze the population exposure of the Tokai- Tonankai-Nakai Earthquake and also to examine the impact from demographic transition. Exposed population change rate is given to examine influence by population decline. Aged 65 and above exposed population is collected to examine impact of population aging.

Another approach is to discuss the impact of demographic transition from disaster recovery. Chen et al. (2009) analyze aged 5-years population census data and develop demographic transition patterns (sustainable, dependent, marginal). These are applied into 1995 Kobe Earthquake and 2004 Niigata Chuetsu Earthquake to study population recovery of affected areas with certain demographic characteristics (Chen et al., 2010b).It is realized that patterns are inclined to perform certain change in population recovery. That is demographic characteristic can be referred as a capability to adapt disturbance. As Adger (2000) noted, we can conclude demographic transition as factor of disaster resilience. Chen et al. (2010c) integrated the idea with population simulation to examine its impact in Tokai-Tonankai-Nankai Earthquake.

Above all, this study intends to apply two mentioned approaches for simulating population exposure and disaster resilience and comparing with current situation (2005-2030), regarded as impact of pre-2030 demographic transition. As Fig. 1 shown, the process is made by 4 portions which are detailed in Sections 2.1 and 2.2

2.1 Simulating population exposure

Instead of applying current population census,

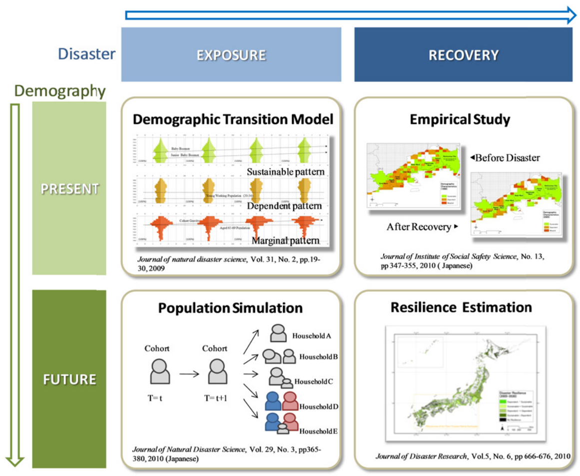


Fig. 1 Research Diagram (Chen et al., 2009, 2010a, 2010b, 2010c)

population simulation is conducted before overlapping with the seismic intensity of the Earthquake beneath Tokyo Metropolitan.

Cohort analysis used in population projection refers to a certain population group born within the same time period. Population is initially classified into 20 age-levels, newborns, and successive 5-year population age aggregates from 0-4 years old to 85 -89 years old, 90 and above. Addition to males and females population, we can divide population again and obtain 40 cohorts. With survivability rate and net-immigration rate every cohort, it is accessible to simulate remaining cohort population number at next time period. By female population able to give birth, annual fertility rate, and new births gender ratio, it is available to acquire newborn population (Fig. 2). All coefficients every prefecture every 5 years period from 2005 to 2030 are applied from Population and Social Security Research (2006). Yet, gender ratio of new births is set at 105.4 (males) to 100 (females), a constant regardless of prefectures or time periods. Based on Population Census 2005, we can continuously conduct 5 times (5 years per time) of cohort component analysis to estimate mesh-based population (Chen et al, 2010a). Yet, combined meshes in 2005 Population Censes are lack for detailed population data. These meshes are considered as inhabited areas in estimation.

We can continuously simulate household based on these mesh-based population simulation. With transition rate of family-typed household head per person, it is available to obtain household number every family type (Fig. 3). Here, aged and single living, aged husband and aged wife, the 20s single living households are especially collected to regard vulnerable household. Integrating seismic intensity and simulated population simulation (density, age,

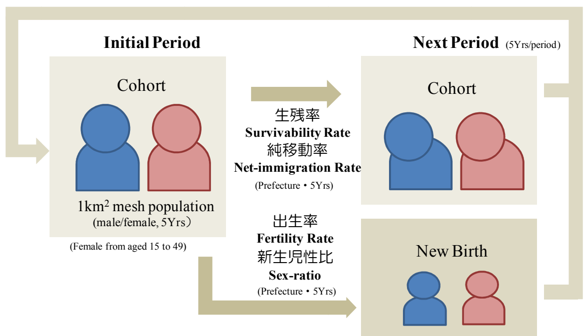


Fig. 2 Cohort component analysis

family) at 1km^2 mesh scale in GIS, it is accessible to estimate population exposure and its structure in a spatial analysis.

2.2 Distinguishing resilience associated with demographic transition patterns

Applying the concept of demographic transition patterns (sustainable, dependent and marginal) is to characterize 2005 and 2030 regional demographic features (Table. 1). Nearest neighborhood method is used to calculate the distance of the DPI (dependent population index) between distinguished meshes and transition patterns (Fig. 4). The shortest one determines the discrimination result. Addition to the empirical studies of the 1995 Kobe Earthquake and the 2004 Niigata Chuetsu Earthquake (Chen et al, 2010b), we can analyze the disaster resilience that present or simulate demographic characteristics that study areas represent. Comparing result in 2005 with 2030, it is accessible to observe the transformation of disaster resilience contributed by demographic transition before 2030.

3. Analyzing population exposure 2030

This study collects 2005 population census mesh-based data of Tokyo, Kanagawa, Chiba and Saitama for simulating the population of Tokyo Metropolitan. The simulation result and seismic intensity are integrated to analyze population exposure 2030 in terms of population, age and household type.

3.1 Population and age

As shown in Fig. 5, the population 2030 is estimated to reach 34.0 million. Contrast to 34.5 million in 2005, an apparent population change is not found. However, two population pyramids constructed by gender 5-years population show a remarkable difference. In the pyramid 2005 (left), it is found that 2 generations of baby boomer (born 1947-1949) and baby boomer junior (born in 1971-1974) occupy largest portions and form the tree-shaped feature. On the other hand, in the pyramid 2030 (right), baby boomer becomes aged 80-84 population and occupies on the pyramid top. Yet juvenile and aged 20-29 young working populations apparently decrease that

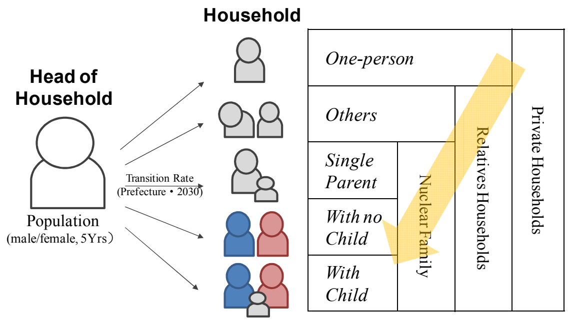
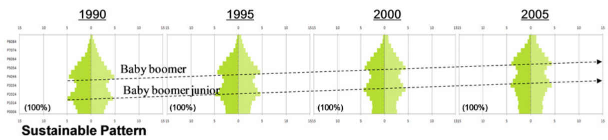


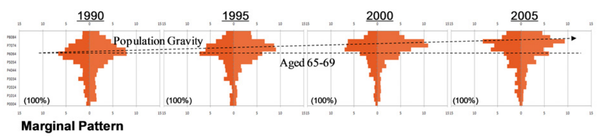
Fig. 3 household estimation with family types

Table 1 Sustainable, dependent, and marginal demographic transition patterns (Chen et al, 2009)



Sustainable Pattern: the sustainable pattern is lead by the baby boomers (born in 1947-1949), baby boomer juniors (born in 1971-1974), and constant young immigration. Young working population and fertility of the next generation are secured.

Dependent Pattern: In dependent pattern areas, ongoing population aging and emigration of young working are expected as unsatisfactory advanced services and fewer human resources weaken region capability.



Marginal Pattern: The marginal pattern shows an unstable transition of every pyramid. Basic services are barely maintained and sufficiency in recovery is unlikely. Human resources and services from outside are required.

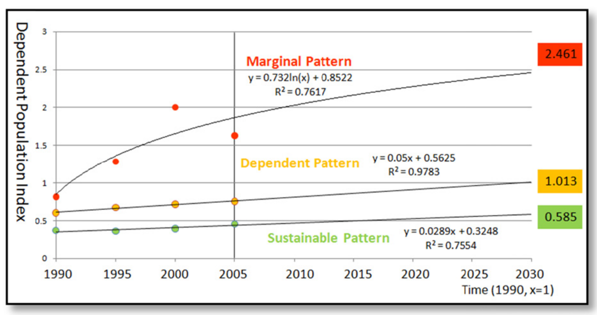


Fig. 4 DPI of transition patterns (Chen et al, 2010c)

transforms the pyramid into diamond shaped gradually.

Fig. 6 presents an unequal spatial distribution of population change rate. Population growing meshes mainly accumulate in most area of Tokyo and the northern Kanagawa prefecture. The rest areas with population growth are spatially associated with railway (green line). For population decline, the west Saitama and east Chiba (Bōsō Peninsula) are covered by meshes with 20% and above population decrease rate.

As shown in Fig. 7, aged 65 and above ratio is above 20% generally. The result indicates the "super aged population society (Fujita, 2007)". Comparing with population growth rate (Fig. 6), it is known that meshes with population growth are inclined to have less population aging. However, Shitamachi (low city) inside core 23 wards is aging than rest areas. It represents that rapid population aging is more expected in suburban and early developed district in Tokyo Metropolitan.

Integrating with population simulation and seismic intensity (the scenario of Northern Tokyo Bay Earthquake) at meshes, we can collect exposed population at scale of seismicity and age structure (Table 2). Intensively exposed population at level "6 Lower" or "6 Upper" is expected to increase due to intensive seismicity distribution and population growth area. Additionally, the main increase is not completely contributed from continuous domestic immigration (Ishikawa, 2002) but associated with aging of baby boomer.

3.2 Household types

Table 3 shows the household exposure by scale seismic intensity and family types. Contrast to nearly 0.3 million population decrease in total, household number are adversely expected to increase 2.1 million households. It means member per household decrease. Among these households, most are related to one-person households rather than nuclear family. In other words, more single living households appear and the general family structure likely become less stable. Family structure transition results into 1.2 million single living households exposed to seismic intensity at scale 6. Considering with age, we can abstract number of aged 65, aged 75 above single living households.

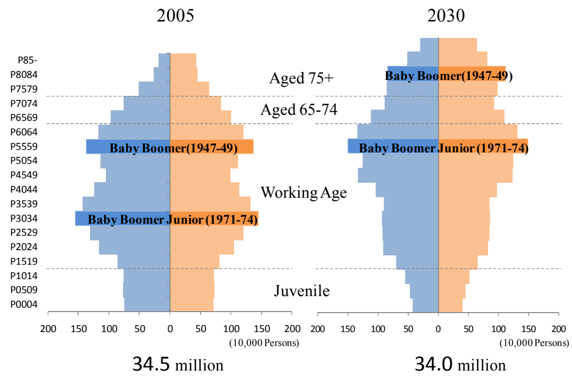


Fig. 5 5-years population pyramids 2005 and 2030

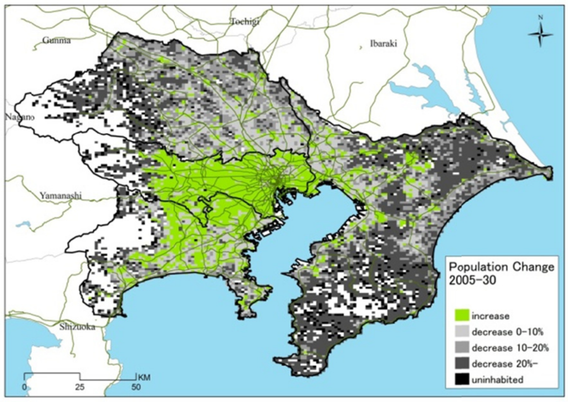


Fig. 6 Population growth rate (2005 and 2030)

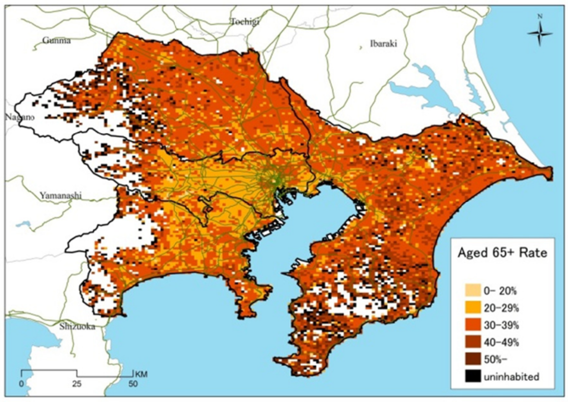


Fig. 7 Aged 65 and above population ratio 2030

Table 2 Population exposure in 2030

Seismic \ Population	Aged 0-14	Aged 15-64	Aged 65+	Aged 75+	Total
6 Upper	37.1 ▲25.5	328.1 ▲28.8	150.5 △62.9	88.8 △54.2	515.8 △8.6
6 Lower	167.9 ▲92.1	1,277.9 ▲145.3	593.3 △246.1	350.8 △210.3	2,039.0 △8.7
5 Upper	64.9 ▲37.4	438,0 ▲82.8	226.1 △88.6	141.5 △84.6	729.0 ▲31.5
5 Lower	9.4 ▲5.4	54.1 ▲19.2	33.1 △9.3	20.8 △9.7	96.6 ▲15.3
4	1.0 ▲0.7	5.5 ▲2.1	3.3 △0.7	2.1 △0.8	9.8 ▲2.0
Total	280.3 ▲161.0	2,103.6 ▲278.2	1,006.3 △407.6	604.1 △359.5	3,390.3 ▲31.5

△/ increase to 2005; ▲/ minus to 2005 (Unit: 10,000)

As shown in Table 4, 2 times of aging and single living household is expected than current situation in 2005. And over half of households are even above aged 75. The increase amount is more than aged husband and aged wife households. It refers that life expectancy extension and family structure lead more aged 75 single living households possibly transformed from aged husband and aged wife households.

3.3 Conclusion

Contrast to 10% of general population decline in Japan, population change rate (2005-30) in Tokyo and northern Kanagawa represents adverse result. Addition to an accidental spatial distribution of intensive seismicity, intensively exposed population is likely to increase. Accompanied with aging of baby boomer, the population aging results into increase of 3 million aging population exposed at scale 6. Considering the elders' physical constraint and less capacity against sociological impact (Ngo, 2001; Frankenberg et al., 2008), that is, self-help is hardly expected.

However, household simulation represents an unstable feature of family structure. More aging and single living households are expected. These households tend to receive less support from family and weaker social network (Mileti, 1999). In this sense, while self-support and support from family become less reliable under demographic transition, mutual aid through community or civic organization is much important than ever.

4. Analyzing resilience with the aspect of demographic transition before 2030

Fig. 8 and Fig. 9 display the distribution of sustainable, dependent, marginal demographic transition pattern in 2005 and 2030. By the above mentioned empirical studies (Chen et al., 2010b), we can discuss regional demographic characteristics in terms of disaster resilience.

4.1 Demographic Transition 2005, 2030

As Fig. 8 shown, most areas are covered by sustainable pattern meshes where are easier to have an effective population recovery with less support. The population recovery of these areas might have

Table 3 Household exposure in 2030

Household / Seismic	One-Person	Relatives Household					Total
		Nuclear Family	With no Child	With Child	Single Parent	Others	
6 Upper	114.4 △31.1	122.3 △10.5	45.7	52.2	24.4	19.7 △6.8	256.4 △47.5
6 Lower	390.9 △91.6	475.2 ▲0	173.4	207.8	94.0	78.8 △25.8	944.9 △110.8
5 Upper	128.5 △57.2	168.9 ▲5.2	62.2	74.1	32.6	29.0 ▲0.5	326.3 △50.1
5 Lower	14.4 △6.5	22.1 ▲0.6	8.3	9.7	4.1	4.2 ▲2.8	40.7 △2.9
4	1.6 △0.6	2.4 ▲0.2	0.9	1.1	0.4	0.5 ▲0.4	4.5 △0
Total	649.8 △188.0	790.8 △4.4	290.4	344.8	155.6	132.2 △28.9	1,572.8 △211.2

△/ increase to 2005; ▲/ minus to 2005 (Unit: 10,000)

Table 4 Vulnerable types of household exposure

Household / Seismic	Aged 20s, Single Living	Aged 65+, Single Living	Aged 75+	Aged 65+, Husband & wife	Aged 75+
6 Upper	15.9 ▲2.7	34.9 △17.9	19.5	25.9 △11.5	15.2
6 Lower	54.8 ▲26.4	126.2 △66.3	71.0	97.8 △31.9	56.2
5 Upper	17.5 △0.5	45.6 △28.7	27.3	36.6 △12.5	22.2
5 Lower	1.8 △0.4	6.1 △3.6	3.7	5.2 △1.9	3.2
4	0.2 △0.1	0.7 △0.3	0.4	0.6 △0.1	0.3
Total	90.3 ▲28.0	213.4 △116.8	121.8	166.1 △57.9	97.1

△/ increase to 2005; ▲/ minus to 2005 (Unit: 10,000)

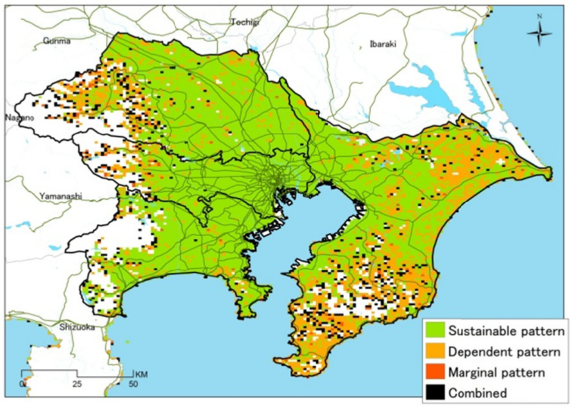


Fig. 8 Demographic Transition in 2005

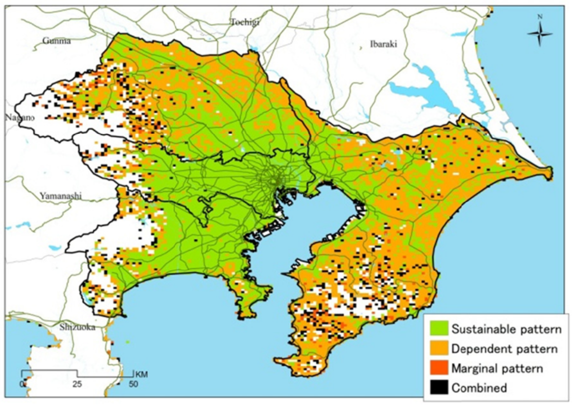


Fig. 9 Demographic Transition in 2030

similar rebound as in Nada Ward after the 1995 Kobe Earthquake, or Jōnai areas of Ojiya city after the 2004 Niigata Chuetsu Earthquake.

Also there are dependent pattern meshes found at western Saitama and partial Bōsō Peninsula. These areas are dependent to the great major recovery projects (such as Land Resettlement Projects, Urban Redevelopment Project in Southern Nagata-Ward) or private sector investment (such as Chūō-Ward). Otherwise, complete population recovery after disaster is hard to be expected, such as Hyōgo-Ward or Northern Nagata-Ward. And there are few marginal patterned meshes found.

Yet, Fig. 9 shows apparent distribution of 3 transition patterns in 2030. Dependent patterned meshes expand and replace where are discriminated as sustainable patterned in 2005. It refers that these areas are accompanied with demographic transition before 2030. The demographic characteristics of these areas might gradually represent the feature of dependent pattern due to less immigration of young working age population and aging of baby boomer.

4.2 Resilience with consideration of demographic transition 2005-2030

Analyzing Fig.8 and Fig.9, it is accessible to collect the meshes with change in demographic transition (See Fig.10). Applying the resilience that demographic transition pattern represents (Table 4) we can visualize impact resulted from demographic transition from an aspect of disaster study (Chen et al, 2010c).

It is found that, meshes in Tokyo and Kanagawa mostly remain sustainable resilience before 2030. Apart from that, similar meshes are only found in prefectural cities of Saitama and Chiba. It refers that these areas might have the potential to complete their population recovery independently and to remain sustainable demographic transition after disaster recovery.

As western Saitama and partial Bōsō Peninsula, great amount of meshes are marked as "sustainable to dependent". From their demographic features, these areas are currently sustainable in resilience. But disaster resilience likely turns into dependent accompanied with future demographic transition. In this sense, for these areas, great major recovery projects or private sector investment is necessary to avoid population decline after disaster recovery.

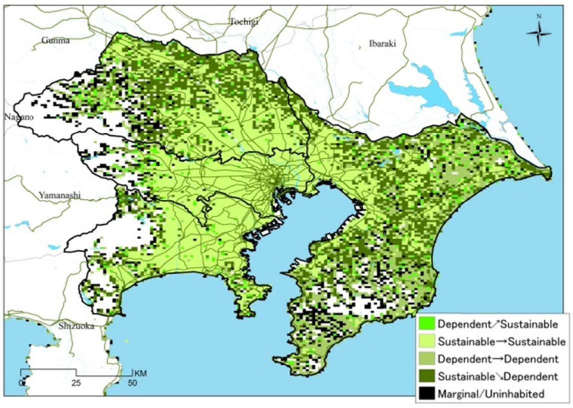


Fig. 10 resilience transformation (2005 to 2030)

Table 4 Resilience transformation associated with demographic transition (Chen et al., 2010c)

Resilience	Characteristics
Dependent 2005 ⇒ Sustainable 2030	Beneficial from the future demographic transition and likely become more resilient in a disaster recovery with less support than current situation
Sustainable 2005 ⇒ Sustainable 2030	The demographic transition is beneficial to complete the population recovery and to contribute a better disaster recovery
Dependent 2005 ⇒ **Dependent** 2030	Still dependent to great amount of public or private support to reinforce their resilience
Sustainable 2005 ⇒ **Dependent** 2030	Disaster recovery of these areas might gradually become difficult than if it happens at a present time and result into a result of decaying areas
No resilience 2005,2030	Completely unexpected to complete a population recovery; but accelerating marginalization turning uninhabited eventually

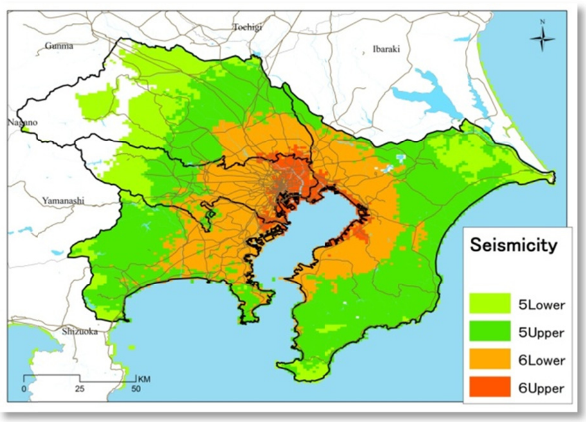


Fig.11 Seismic intensity

The result delivers an important message that demography factor is dynamic in vulnerability assessment. Current situation is not comprehensive enough to develop long-term disaster management against expected catastrophe. And this is why adaptation strategy is aimed to adjust the affected object itself to be more capable for disturbance.

5. Developing Adaptation Strategy to reinforce resilience under demographic transition

Seismic intensity (Fig. 11) is overlapped with resilience (Fig. 10) to discuss adaptation strategy following regional characteristics. For the 23 Wards in Tokyo, Kawasaki city and Yokohama city in Kanagawa, are estimated to extend population growth inclusive and to remain in a sustainable pattern but exposed to intensive seismicity. It refers that these areas are more capable to complete population recovery after disaster, yet aging of baby boomer and unstable family structure might increase 3 million aging population exposure, and 0.8 million aging single living households. In this sense, "sustainable maintenance" is the main purpose to relief the impact and to accelerate the recovery.

Business continuity planning (BCP) works to avoid business from being severely interrupted, and to help business to restart as soon as possible once interrupted. Hayashi (2009) found that in disaster management, BCP can reduce impact and enable effective recovery. The eventual goal of BCP is to reinforce the resilience of the whole organization. In this sense, BCP has become indispensable to enterprises and municipalities while coping with extension disruption, crisis, and disaster. To take advantage of the self-sustaining resilience of this region, the adaptation strategy, e.g., BCP is urgent and necessary for ongoing demographic transition and infrastructure centralized regions.

As western Saitama and partial Bōsō Peninsula, possibly decay and transform from sustainable patterned to dependent patterned. Especially west coast of Bōsō Peninsula is exposed to intensive seismicity. An alternative solution is to rely on the aging population structure to improve resilience at these regions independently. That is because while self-aid and support from family network are less reliable accompanied with future demographic transition, reinforcement of mutual help could be a practical approach. In this case, instead of intensive hardware investment, community capability reinforcement is suggested as one principle of adaptation strategy. For example, community activity in participatory community disaster risk management (Bajek et al., 2008) or a strong local network (Ota et al., 2008) is suggested to improve local capability.

6. Conclusion

For a population declining society of Japan, Tokyo Metropolitan obviously represents a unique case to examine the impact in a demographically mature metropolitan. In this paper, estimations of population estimation 2030 and three demographic transition patterns are conducted to examine the impact of demographic transition with the aim to develop the corresponding adaptation strategy.

According to the population estimation by cohort component analysis, though the growth of population exposure is rare contrast to whole Japan in 2030, baby boomer aging and young immigration decline result in rapid aging demographic structure and increase another 2.5 million aged 75 and above population exposed by intensive seismic intensity at scale 6 and above. Additionally, demographic transition associated with family structure results into more unstable family structure of single elder living households. Another 1 million household of single living elders are expected at areas with intensive seismicity. Most of all, demographic estimation delivers a critical message that mutual aid through community or civic organization is much important to cope with less reliable self-support and support from network of family or relatives.

Overlapping current and estimated distribution of the demographic transition patterns (sustainable, dependent, and marginal), it is accessible to observe regional demographic transition and the possible impact in term of disaster resilience. It is found that 23 Wards, Kawasaki city and Yokohama city are inclined to remain sustainable patterned which implies these areas are more capable to complete disaster recovery independently. Yet, regarding exposed population growth and intensive seismicity, BCP is recommended to relief the initial impact and to accelerate the recovery. On the other hand, western Saitama and partial Bōsō Peninsula may decay from sustainable patterned to dependent patterned that reflects that the areas might become less capable to rebound back to original situation unless great recovery projects or private investment is applied. In term of risk governance, community activity in participatory community disaster risk management or a strong local network is suggested to reinforce social resilience with the consideration of future demographic transition in the Tokyo Metropolitan.

Acknowledgements

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将来人口変動を考慮する首都直下地震の適応戦略に関する研究

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要　旨

本研究は，首都直下地震に備えるために，首都圏の将来人口変動を考慮し，被害と復興を中心とする評価手法と適応戦略を提案することを目的とするものである。国勢調査の地域メッシュ統計データを用い，コーホート要因法で2030年の人口推計を行い，首都直下地震のゆれに見舞われる震度別暴露人口（人口密度・年齢構造・家族構成）を求めた。2005年の集計結果により，震度6以上の暴露人口は増えており，特に団塊世代の老化ともなう高齢人口。かつ，単身高齢者の急増のために，自助と家族内の互助が弱くなる事によって，将来人口変動による影響は明らかにした。1995年の阪神淡路大震災と2004年の新潟県中越地震の事例研究から，被災前人口特性と復興後人口回復の検証に基づき，将来人口特性の変動とともにレジリエンスが変わる地域を抽出してきた。首都圏内の震度分布・暴露人口構造・レジリエンスに基づき，地域毎の適応戦略として，事業継続計画とコミュニティネットワークの強化手法についての検討を行った。

キーワード: 人口減少，高齢化，レジリエンス，首都直下地震