Spatial Structure of Public Service Facilities and Its Coupling Relationship with Population Distribution Based on GIS:

- Case Study of Central Tokyo, Japan -

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1. INTRODUCTION

Public service facilities are generally used to meet people's daily requirements with government investments. They belong to social service facilities and mainly including medical facilities, educational facilities, welfare facilities, cultural facilities, etc., which are significant to improve residents' quality of life and the urban living. The quantity and quality of public services that can be served to the public are influenced by the spatial structure of facilities and distribution of population. Therefore, this paper aims at building a coupling model between spatial structure of public service facilities and population distribution to measure their matching degree based on GIS. Meanwhile, along with providing evaluation method to Beijing which exist numerous problems in public service facilities allocation, this study also draws lessons for structural optimization from the case study of Tokyo.

With the new round revision of Beijing's (China) urban master plan has been spread out in 2014, the evaluation of implementation status and exploration of promotional strategy for public service facilities have been a core content of constructing livable city. In view of current development situation, differences between spatial distribution of the housing and its surrounding public service facilities are increasingly prominent. Difficulties in the use of facilities with Beijing's characteristics have become the focus problems of people's livelihood. For example, many facilities are existing problems of uneven distribution and insufficient facilities, especially for medical and basic educational facilities in the community level (*Jinfeng REN et al., 2012*). They have own peculiarities in spatial structure, variation trend and association with population. In this aspect, Tokyo is more mature in the planning and management of public service facilities. In 2013, the number of hospital per 100,000 people in Tokyo is 1.6 times of Beijing, and the numbers of primary and middle school per 100,000 people of right age are more than Beijing, etc (*Wenzhong ZHANG, 2016*).

The purpose of public service facilities is to provide services and pursue to maximize public benefits. The maximization of public benefits is mainly reflected in the minimum consumption of residents to a facility which is related to the service population and average distance to a facility (*Changkui SHI, 2015*). The measure of coupling fuses these two core elements. It expresses the internal consistency of two geological matters in one space and the degree of interaction (*Chenghao YANG, 2013*). At present, coupling analysis has been used in urban planning fields. *Miaoxi ZHAO et al. (2014)* discussed the coupling relationship between information technology level and public transportation; *Feng HAN et al. (2009)* focused on the coupling mechanism of urban spatial structure and traffic organization and analyzed associated factors; *Søren Kjær Foged (2016)* analyzed the relationship between population size and the contracting out of public service delivery in local governments, etc.

From these relevant literatures, the analysis of coupling relationship has been applied in parts of urban space planning and management. But studies for space of facilities from perspectives of population and distance were relatively less. Even existing in studies, scholars were mainly focusing on the macro level of city. It lacked of medium level view like blocks or residential quarters which caused inaccurate evaluations for planning and policy guidance. Therefore, this paper takes central Tokyo as a case study and reveals spatial structure of various facilities. Based on this, we build a coupling model by using urban chome as the basic unit of population distribution to discuss the coupling relationship between spatial structure of public service facilities and population distribution. This study will provide a certain scientific basis for measuring reasonable degree of facilities and give references for implementation evaluation and policy-making in Beijing through the case study of Tokyo.

2. STUDY AREA AND DATA

This paper selected central Tokyo (units of 23 wards) as the case study. 23 wards are the central of politics, economy and culture of Tokyo, which cover an area of 621.81 km^2. The population of these wards is over 9 million people and their distributions have changed with the reform of urban functions and structure. The spatial structure of public service facilities and population distribution will be firstly analyzed. Secondly their coupling relationships based on coupling degree model will be discussed to evaluate its implementation effect.

The data has been used in this paper mainly comes from the data and materials that official issued by Japanese governments and departments. (1) The information points (shape file) of medical facilities, primary schools, welfare facilities, cultural facilities and urban parks in the unit of 23 wards from the national land data published by Ministry of Land (*Figure.1.*). There are 27526 points in total and each point contains the information of name, location and category. We can acquire the number of each public service facility in each chome through the data collecting. (2) The land use map (shape file) of 23 wards from national land data was published by Ministry of Land. It will be used to make comparison between population distribution and its land use type, which has significant impacts on evaluation of coupling relationship. (3) Finally we use the administrative boundary of units of 23 wards and chomes respectively (shape file) from portal site of official statistics of Japan. We convert the polygon of chomes into points in order to make visualization analysis. Useful information in these data is mainly including the land area and population of each chome, etc., which are required parameters in calculating the coupling degree.

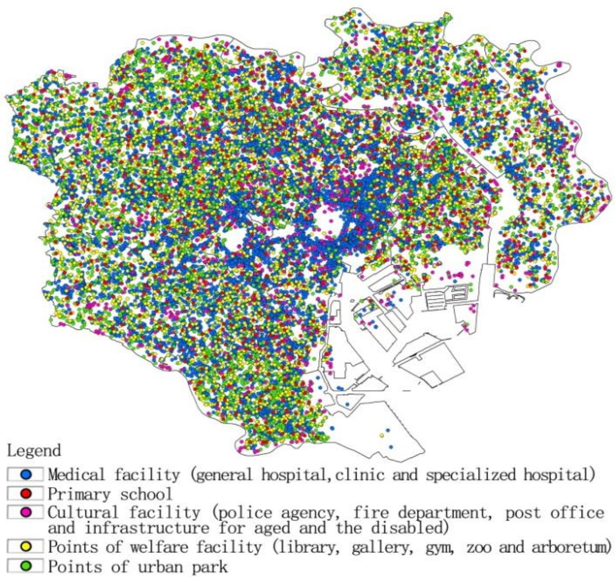

Figure.1. Spatial layout of points of public service facility

3. METHODOLOGY

Kernel Density Analysis

Kernel Density Analysis is a significant method of spatial elements analysis in ArcGIS. It mainly used to calculate the concentration of specific elements within their scope of neighborhood. This method takes the location of a specific point as the center and makes distribution of its properties in the range of specified thresholds. It means in a circle with the radius r, the density is biggest in the center and gradually weakened outwards (*G. Modica et al., 2012*). Finally the density map of points will be formed by the same way of superposition and smoothing process in a certain area.

Coupling Degree Model

Coupling relationship expresses the internal consistency of two geological matters in one space. Hence, we need to estimate the degree of interaction and influence from each element through the calculation of coupling degree. In the process of modeling between public service facilities and population, two parameters of service population and the distance to a facility will be mainly used (*Huitong WANG et al., 2014*). Based on this, we build the basic model of calculating coupling degree as follows:

$$C_c = P_c \times D_c \qquad (1)$$

C_c denotes the coupling degree; P_c denotes the population parameter; D_c denotes the distance parameter.

This paper selects chomes of 23 wards as the basic unit of population concentration area, and their surrounding public service facilities will have great impacts on residents' quality of life directly in chomes. Each ward is divided into several chomes which means the service capability of public service facilities in each chome are determined by the proportion of population in each chome to the total population of its ward. However each kind of facility has many species which is hard to determine serviced areas. Therefore, we adopt P_m which denotes the population of chome with highest service capability in whole city and treated as the benchmark 1 ($P_m \geq P_{ch}$) (*Joseph AE et al., 1982*). We can get population parameter by the equation:

$$P_c = \frac{P_{ch}}{P_m} \qquad (2)$$

P_{ch} denotes the population of each chome; P_m denotes the population of chome with the highest service capability.

Due to the locations of facilities are random relatively in wards and chomes, and the housing distribution in chome is difficult to measure. Hence, we adopt the variable of average distance to represent the distance from housing to facility. Meanwhile, research objects in this study refer to a large class of facility in general which focus on an overall relationship with population. Therefore, in the calculation of distance parameter in the level of chome, we assume that facilities are distributed randomly. Based on this, we use the average distance under the condition of random distribution as one of variables in distance parameter D_c (*Marcon E et al., 2003; Canfei HE et al., 2007*). The distances are related to the land area of chome and number of each facility.

$$D_{average} = \sqrt{\frac{A_c}{N_f}}/2 \qquad (3)$$

$D_{average}$ denotes the average distance to each facility; A_c denotes the land area of each chome; N_f denotes the number of each facility. In practices, each facility has its own relatively appropriate service radius according to relevant specifications and plans, and it will cause inconvenience to residents when the distance exceeds the radius. Therefore, we involve the ratio of service radius into above average distance from house to facility to represent the distance parameter:

$$D_c = 2R_m / \sqrt{\frac{A_c}{N_f}} \qquad (4)$$

R_m denotes the service radius of each public service facility; A_c denotes the land area of chome; N_f denotes the number of each facility in chome. The more distance, the lower is the distance parameter. Above all, we build the coupling degree model between public service facilities and population is following by putting (2) and (4) into (1):

$$C_c = \frac{2R_m P_{ch}}{P_m \sqrt{\frac{A_c}{N_f}}} \qquad (5)$$

C_c denotes the coupling degree of each chome; R_m denotes service radius of each facility; P_{ch} denotes population of chome; P_m denotes the population of chome with highest service capability; A_c denotes land area of each chome; N_f denotes the number of each facility in chome.

4. RESULTS

4.1. Spatial structure analysis of public service facilities

After making a classification of information points of public service facilities, we analyze the kernel density by using ArcGIS10.0 respectively (*Figure.2.*). The medical facilities are existing agglomeration phenomenon in certain degree, districts with higher density of distribution are mainly including Chiyoda, Chuo, Shinjuku and Shibuya, which took 800 meters as the radius of searching density. They are radiating out from center to periphery. From the land look, the density of medical facilities is higher in commercial area, especially for the proportion of daily medical services like dentistry and internal medicine are relatively high. Primary schools have been evenly spread in various land use areas and its form of space presents an obvious decentralized structure with multiple cores. These cores are distributed in the regions outside the core areas. Denser regions of primary schools are mainly located in high-rise residential areas, quasi industrial areas and a few commercial areas. The degree of balanced distribution of cultural facilities is highest and spatial structure is scattered dot form distribution. Its clustering is not obvious and distribution is consistent in various land use areas. The spatial structure of welfare facilities is similar with primary school which presents a decentralized structure with multiple cores. Denser regions of welfare facilities are mainly located in high-rise residential and quasi industrial areas. Urban parks are easier clustered in outside regions, such as Itabashi and Ota districts. Core areas like Bunkyo are reflecting a small amount of clustering. Parks are mainly located in low-rise residential and industrial areas which basically achieve high space coverage for urban areas.

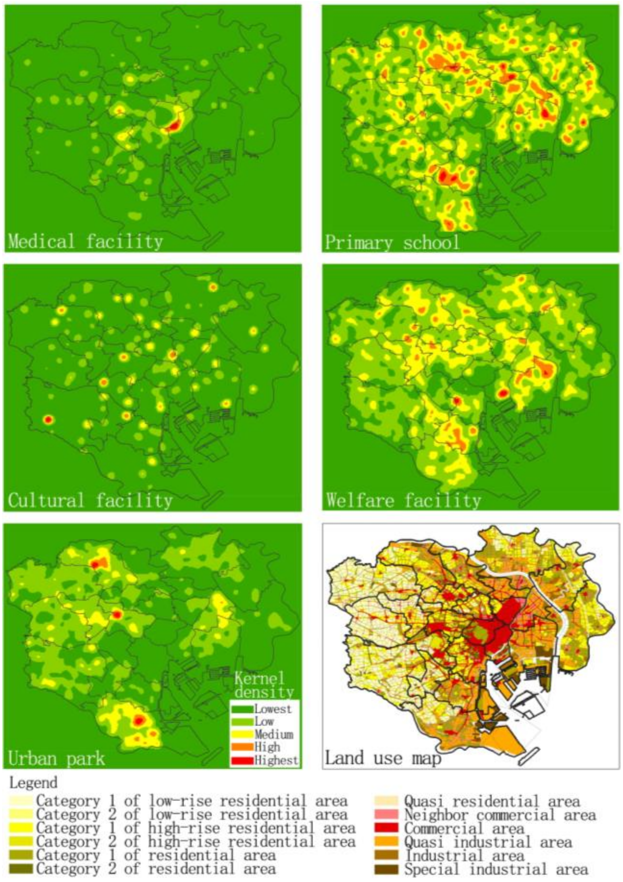

Figure.2. Results of kernel density for public service facilities

4.2. Population distribution

In macro level, the number of population is centered in Chiyoda, Chuo and Taito districts and increasing gradually from center to outside. A larger proportion of the population is concentrated in Edogawa, Adachi, Nerima, Setagaya and Ota districts, which is closely related to the current life mode of separation of workplace and residence in Tokyo. Making a comparison with land use, populations are mainly clustered in residential areas and different categories of residential area reflect various characteristics of density. Districts of Adachi, Katsushika and Edogawa are strongly correlated with industrial area. Most of them are high-rise residential area and a large number of populations have gathered in order to meet the living demand of employment. In the western regions such as Nerima, Suginami, Setagaya and Ota districts, etc., where gathered a large number of populations in the land use type of low-rise residential area. However in central regions like Toshima, Shinjuku and Shibuya districts, the lands are mainly used in high-rise housing construction, but population density is lower due to reasons of near the core commercial areas, high housing prices, etc. In medium level, the feature of population distribution in chomes is basically similar with macro level. Chomes with higher degree of population agglomeration are basically distributed evenly in their districts, but they generally appear a trend of increasing gradually from internal to external on the space (*Figure.3.*).

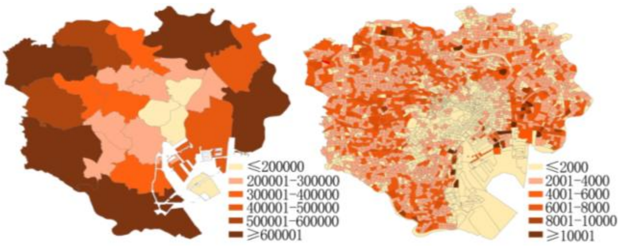

Figure.3. Results of population distribution in central Tokyo

4.3. Coupling relationship between facilities and population

With the urban development and space extension of Tokyo, the distributions of facilities and population basically gathered in regions outside the urban core areas and they are gradually extended. The harmonious development of these two ones is significant for improving residents' quality of life and optimizing spatial structure of urban. Facilities tend to cluster moderate in areas with high population density, which is benefit for more residents' daily needs. They should adapt to the features of population distribution and present moderate scattered layout to achieve efficient coverage for residents' life. From above current status, public service facilities were in agreement with population as a whole. But whether their relationships matched in the medium level of chomes, and where the mismatches occurred. Further research is still required to evaluate these questions in chomes.

In practice, various facilities have different optimal service radius because of their own properties. This paper selects optimal service radius of each facility according to planning indexes from several actual cases. In addition, we select medical facility, primary school and welfare facility as case studies to make deeper analysis on coupling degree with population due to the depth of relations to daily life and available data. Firstly, we put organized data into equation (5) to calculate the coupling degree. Then, we pick those chomes which coupling degrees are less than 0.5 as areas that the coordination relationship is low. Using software of SPSS22.0 and ArcGIS10.0 to calculate overall and average degree of these facilities and show their spatial distributions. The schematic diagrams of coupling are showed in *Figure.4*.

Overall, the coupling degrees between public service facilities and population are relatively high. The average coupling degree of medical facilities, primary schools and welfare facilities are 2.41, 1.51 and 1.90 respectively. Medical facilities' coupling degree is highest and primary school is relatively low. From perspective of spatial structure, chomes with relative low coupling degrees of these three facilities are mainly located in city center and sub-center. But the land uses of these districts are commercial purpose that their public service facilities are mainly providing services

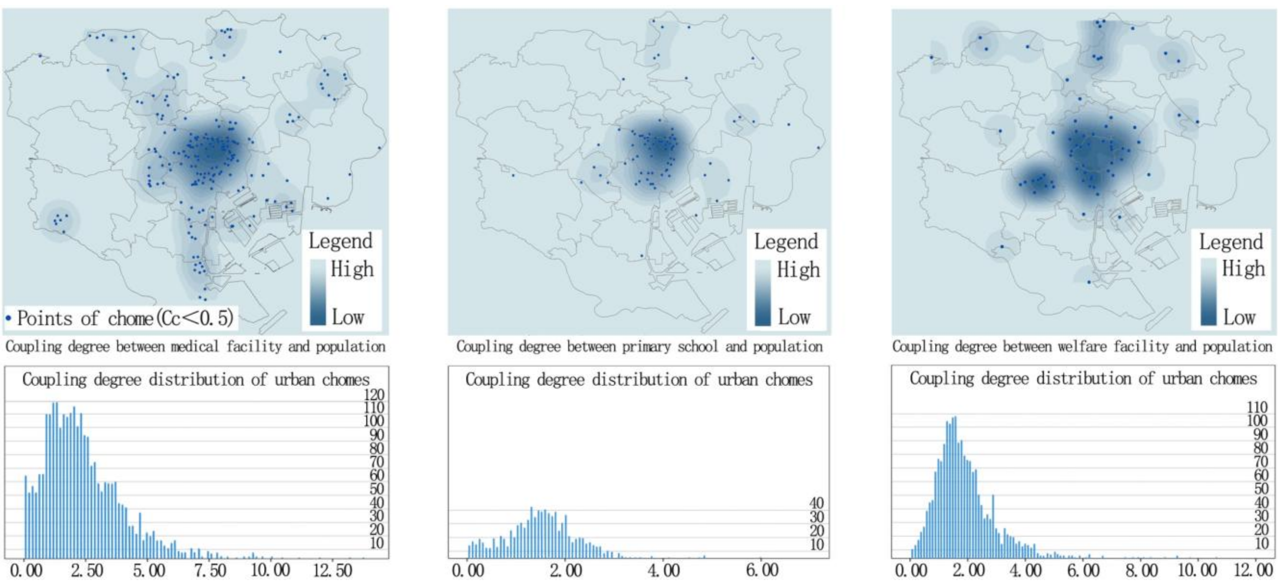

Figure.4. Coupling relationship between facilities and population

for peripheral residents. Hence, these chomes are not treated as the main areas of coupling evaluation. Focusing on others non-commercial use areas, chomes with relative low coupling degree of medical facilities are clustered in parts of residential areas in Setagaya district, residential and industrial areas in Adachi and Katsushika districts, and industrial areas in Shinagawa and Ota districts. Chomes with relative low coupling degree of primary schools are mainly clustered in parts of residential and industrial areas in Adachi district, and industrial areas in Edogawa and Koto districts. Chomes with relatively low coupling degree of welfare facilities are mainly clustered in parts of residential areas in Itabashi district, residential and industrial areas in Adachi district, and industrial areas in Edogawa district. These regions are existing mismatch to varying degrees and the couplings of different facilities are distinguishable (*Figure.5.*). It will disturb the comfort and accessibility of residents' daily life.

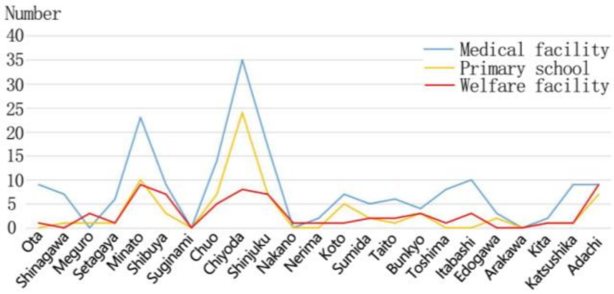

Figure.5. Chomes in each ward which the degrees are lower than 0.5

5. DISCUSSION AND CONCLUSIONS

Spatial structure analysis of public service facilities and its coupling degree with population is one of methods for evaluating implementation and developing optimization strategies of facilities. Results show, (1) Spatial structure of public service facilities in Tokyo are relatively balanced basically and clustering in local areas to some degree, like the medical facilities and urban parks. (2) There are differences of clustering areas among various facilities, which medical facilities are mainly concentrated in commercial areas, primary schools, welfare facilities, and urban parks are mainly concentrated in residential and industrial areas, cultural facilities are more balanced in all areas. (3) The distribution of population in Tokyo reflects a trend of increasing gradually from internal to external on the space, but it is more balanced in the level of chome. Meanwhile, except for residential areas, industrial areas present a certain size of population agglomeration. (4) In urban chomes, the coupling relationship between public service facilities and population is well generally, parts of mismatching phenomenon mainly appear in residential and industrial areas of the outskirts of urban, and there are close correlation with density of facilities.

This model also can be applied in Beijing to evaluate the allocation of facilities based on population distribution, and find areas do not match. Results from Tokyo provide useful inspirations to manage public service facilities of Beijing. A relatively balanced allocation of facilities, proper numbers and be constructed in time will have positive effects on the improvement of coupling degree, especially for the construction of local medical facilities and parks in industrial areas. Compared to the research unit of urban chome, spatial structure of facilities in Beijing can be considered to optimize from a relatively micro-perspective like block or residential quarter, which has closer relations to residents' daily needs.

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GIS に基づく公共施設空間構造および人口分布の相関関係に関する研究

- 東京 23 区を例として-

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キーワード：　公共施設における空間分布；人口分布；結合（カップリング）；GIS；東京

概要:

本稿では東京 23 区を研究区域とし、対象区域内の公共施設の位置の点としての情報データと、区から丁目までの面の情報データを利用し、核密度分析や建設結合モデルの方法を用いて、東京での各種の公共施設の空間的構造、人口分布の特徴、及び町丁目という中間的な単位においての公共施設の空間的な構造と人口分布の関係の結合度を研究、分析した。主な結果として、①東京都では各種の公共施設の空間的構造は比較的にバランスよく配置されており、局部では密集しているところも見られる。特に医療施設や都市公園の密集割合が比較的に高い。②各種の公共施設の密集地が異なっており、医療施設は商業地域に密集しているのに対し、小学校、福祉施設や都市公園は住居地域と工業地域に密集し、また文化施設は各区内に比較的に均等に分布している。③東京の都市人口分布は中心部から外側に向かって徐々に増加している傾向がみられるが、各区内の町丁目区画における人口分布は比較的に均等的であることがわかる。また、住居地域以外に、工業区域にもある程度の人口の密集が見られる。④町丁目の区画においては、各公共施設の空間的分布と人口分布の結合度は全体的によく、人口との不均衡が見られる一部の施設は主に都市の外側の住居地域と工業地域に見られ、そして施設も密度ともある程度相関している。

北京市では、東京との公共施設の計画と管理の面を参考にすることができる。東京都において実例分析からわかるように、公共施設の空間的な均衡分布と建設の即時性が施設、特に地方における医療と産業地域の施設の建設と人口の結合度おいての向上にプラスな作用をもたらしている。また、本論文は東京での実例の分析することで、北京における中間的なレベルでの公共施設と人口の相互作用の測定方法のヒントを見つけることができた。

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