

Spatial diffusion of the HIV/AIDS epidemic in Japan based on the national HIV/AIDS surveillance

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ABSTRACT

The aim of this paper is to clarify and model the spatial aspects of the HIV/AIDS epidemic in Japan to predict the present and future states of geographical distribution of HIV cases and spatial relationships in HIV transmission. We confirmed and predicted significant geographical variations in the HIV epidemic in Japan at a local level. Implications for planning preventive actions and improvement of surveillance system are discussed based on the results.

Keywords and phrases: epidemic model, spatial diffusion, HIV/AIDS surveillance, Japan

1.0 INTRODUCTION

Recently a decline in the number of new AIDS cases has been reported in some industrialized countries. Although Japan has one of the lowest rates of HIV/AIDS cases among industrialized nations, the number of HIV/AIDS cases in the country has been steadily rising (Matsuyama et al., 1999). In the earlier phase of the HIV/AIDS epidemic (until around 1990), most of cases were reported from Tokyo and its surrounding prefectures. However, spatial diffusion of the epidemic is becoming apparent as the epidemic develops. We should now take note of the rising risk of HIV/AIDS outside the Tokyo metropolitan area. In this situation, the information concerning local epidemic states are necessary for supporting national/local health agencies planning preventive actions against HIV/AIDS expansion in Japan.

The aim of this paper is to clarify and model the spatial aspects of the HIV/AIDS epidemic in Japan to predict the present and future states of geographical distribution of HIV cases and spatial relationships in HIV transmission. Though several future projections of HIV/AIDS cases in Japan have been already conducted by using trend analysis (Hashimoto et al., 1993) and micro-simulation (Hashimoto et al., 2002) at the national scale, these attempts do not include any spatial dimension.

We analyse the processes of HIV/AIDS spatial diffusion based on HIV/AIDS surveillance, which began in 1984 and was legalized in 1989, with the aid of GIS mapping and spatial modelling techniques. Firstly we describe the trend of HIV/AIDS diffusion in Japan from 1985-2001, and secondly we geographically model the HIV epidemic sequences taking into account the spatial transmission of HIV in order to project

future trends. Finally we discuss the geographical implications for policy making based on the modelling results.

2.0 HIV/AIDS DIFFUSION IN JAPAN

The national HIV/AIDS surveillance has annual regional counts for cases classified according to the 47 prefectures for the years 1985 to 2001. Mapping these data reveals the typical spatial diffusion patterns which other developed countries have experienced: contagious diffusion (from near to far places) and hierarchical diffusion (from more to less densely inhabited places) (Gould, 1993; Smallman-Raynor et al., 1992). Most reports of HIV/AIDS cases have concentrated in Tokyo and its surrounding prefectures. At the same time, a rising number of cases has been observed in peripheral prefectures having large regional centres and prefectures neighbouring these centres.

However, the reported location of cases does not necessarily correspond to place of residence. In particular, the large number of reported cases in Tokyo is likely to reflect the large number of patients visiting Tokyo hospitals from other prefecture. We developed an allocation model to adjust the locational bias to estimate geographical distribution of cases by their living places. The model was calibrated with data sets of hospital visits surveys. Because the raw number of reported HIV cases is likely to be an underestimated figure of real HIV prevalence, the size of HIV cases was also adjusted by multiplying 2.4. This value is estimated by the difference between reported and expected AIDS cases until 1997 based on the 10 year-average incubation period assumption, though the value is lower than the estimated cover rate, 5.1, of the reported HIV cases by Hashimoto et al., (2002) and Matsuyama et al., (1999). While the adjusted data show a slightly wider spread of HIV/AIDS cases than the original data, the fundamental spatial structure and diffusion pattern are unchanged.

Another set of geographical data contained in the HIV/AIDS surveillance is the estimated country where the infection is thought to have been acquired (in Japan or abroad). The national trend shows that the number of infections acquired in Japan has risen considerably while the number of cases of infection acquired abroad has been almost constant. In other words, the proportion of overseas infections (defined as the number of cases infected in overseas countries divided by the total number of cases) has decreased as the domestic transmission of HIV has been activated.

We investigated regional differences in estimated countries of acquired infection by using personal records for the surveillance conducted during the years 1999 to 2001. The proportion of cases of overseas infection was higher in peripheral areas than in the Tokyo metropolitan area, while the number of newly reported cases during the three-year period was the highest in the Tokyo metropolitan area. Unfortunately, we could not confirm the domestic geographical channels of HIV/AIDS transmissions among people living in different areas in Japan, due to restrictions on the surveillance data.

3.0 A SPATIO-TEMPORAL MODEL OF HIV TRANSMISSION

Spatial interaction by inter-regional flows leads to inter-regional contacts of people to regulate spatio-temporal patterns of diffusion processes. A considerable number of researches have tackled with the modelling of the processes in the context of infectious diseases including HIV/AIDS (Cliff and Haggett, 1988; Thomas, 1992; Williams and Rees).

Following Nakaya (1994, 2001), we built a simple HIV epidemic model taking account of spatial interaction to reconstruct and predict the distribution of HIV cases.

$$\begin{aligned}
 newI_{i,t}^J &= \beta_i S_{i,t}^J \sum_j m_{ij} (I_{i,t}^J + I_{i,t}^F) / n_{i,t} + \gamma_i O_{i,t} \\
 I_{i,t+1}^J &= \mu^J I_{i,t}^J + newI_{i,t}^J \\
 S_{i,t+1}^J &= \nu^J S_{i,t}^J - newI_{i,t}^J \\
 m_{ij} &= p_j \exp(-\delta d_{ij}) / \sum_k p_k \exp(-\delta d_{ik})
 \end{aligned}$$

where

$newI_{i,t}^J$ is the number of new Japanese cases of HIV of prefecture i at year t ,

$I_{i,t}^J$ and $I_{i,t}^F$ are the number of Japanese and foreigner infectives of prefecture i at year t , respectively,

$S_{i,t}^J$ is the number of Japanese subjectives of prefecture i at year t .
 m_{ij} is the inter-regional contact rate of a person in prefecture i with a person in prefecture j ,
 $n_{i,t}$ is the size of risk population in prefecture i at year t ,
 $O_{i,t}$ is the number of overseas travellers from prefecture i at year t , and
 p_j is the population size of prefecture j as the attractiveness for inter-regional contact,
 d_{ij} is the time-distance (in hours) from prefecture i to j , and
 $\beta_i, \gamma_i, \mu^J, \mu^F, \nu^J$ and δ are parameters.

In prefecture i , each susceptible contacts β_i persons sufficient for infection of HIV following the gravity model, the contacted persons are allocated for each prefectures where the infective rate is $(I_{i,t}^J + I_{i,t}^F) / n_{i,t}$. γ_i is the infectious rates acquiring HIV in foreign countries and estimated by the 1999-2001 personal record. μ^J, μ^F, ν^F and $n_{i,t}$ are calculated by the incubation period of AIDS and cohort change rates of sexually active populations based on the national population projection. As for the update of foreigner HIV cases, we used a similar equation to the one for Japanese HIV cases, but regarded the series of new cases as an exogenous variable. Since a unnatural sudden rise of Foreigner HIV cases was reported in 1992, the value as of 1992 is set by the average of 1991 and 1993 cases.

The major problem in using such a theoretical epidemic model is the estimation of risk population size. Unlike in Western Europe the peak size of AIDS has not still been observed in Japan, so that we could not infer this value from past epidemic trends. We gave a value of 0.147% for the sexually active population defined by males and females aged 15-49. The rate almost corresponds with the estimated HIV prevalence of Belgium, where the major modes of HIV transmission are similar to Japan (negligible infection size of IDU drug usage and relatively large size of heterosexual transmission) through the use of the precedent analysis (Thomas, 1999, 2000).

We simplified further the calibration process of the model by assigning parameter values a priori based on the previous descriptive surveys or precedent modelling results. The remaining task of calibrating the model is the inference of β_i and δ . If we predefine δ , then the model become a simple regression model without constant (The dependent variable is $newI_{i,t}^J - \gamma_i O_{i,t}$ and the independent variable is $S_{i,t}^J \sum_j m_{ij} (I_{i,t}^J + I_{i,t}^F) / n_{i,t}$). For calibrating the simple model, we can calculate the number of subjectives and infectives based on the past series of reported cases. In some prefectures, the numbers of cases are too small to obtain a reliable estimator. It is also expected that the speed of infection will vary regionally. Therefore, we estimated the regional variation of the infection parameter, using a localized calibration technique, GWR (geographically weighted regression) (Fotheringham et al. 1997). The method deduces regional estimators of parameters by a kind of moving window that is specified by the geographical weighting kernel. We developed an adaptive kernel to vary the spatial range of weighting due to the number of cases in the kernel window. We applied the GWR model to the adjusted series of reported cases from 1991 to 2001. Finally we decided the distance decay parameter among listed values as the one by which the model attains the best goodness-of-fit of the deterministic simulated series from 1991 to 2001 with the initial condition defined by the 1985-1990 reported values.

The terminal model fitted well the adjusted space-time series of reported HIV/AIDS cases from 1991 to 2001. Assuming several exogenous conditions, such as the number of overseas travellers from Japan, are unchanged after 2001, we obtained a geographical projection for HIV cases until 2025. According to the results, the trends of neighbouring and hierarchical diffusion will last for the next several decades (Figure 1). By using this model, we also found that infections in the metropolitan areas, such as Tokyo and Osaka, lead to a rapid increase in HIV infection in peripheral regions, as do infections acquired abroad. The size of newly reported cases will be the largest around 2010 (Figure 2). The number in Kanto region which almost corresponds to the Tokyo metropolitan area will become lower than those in other regions from 2008 (Figure 3).

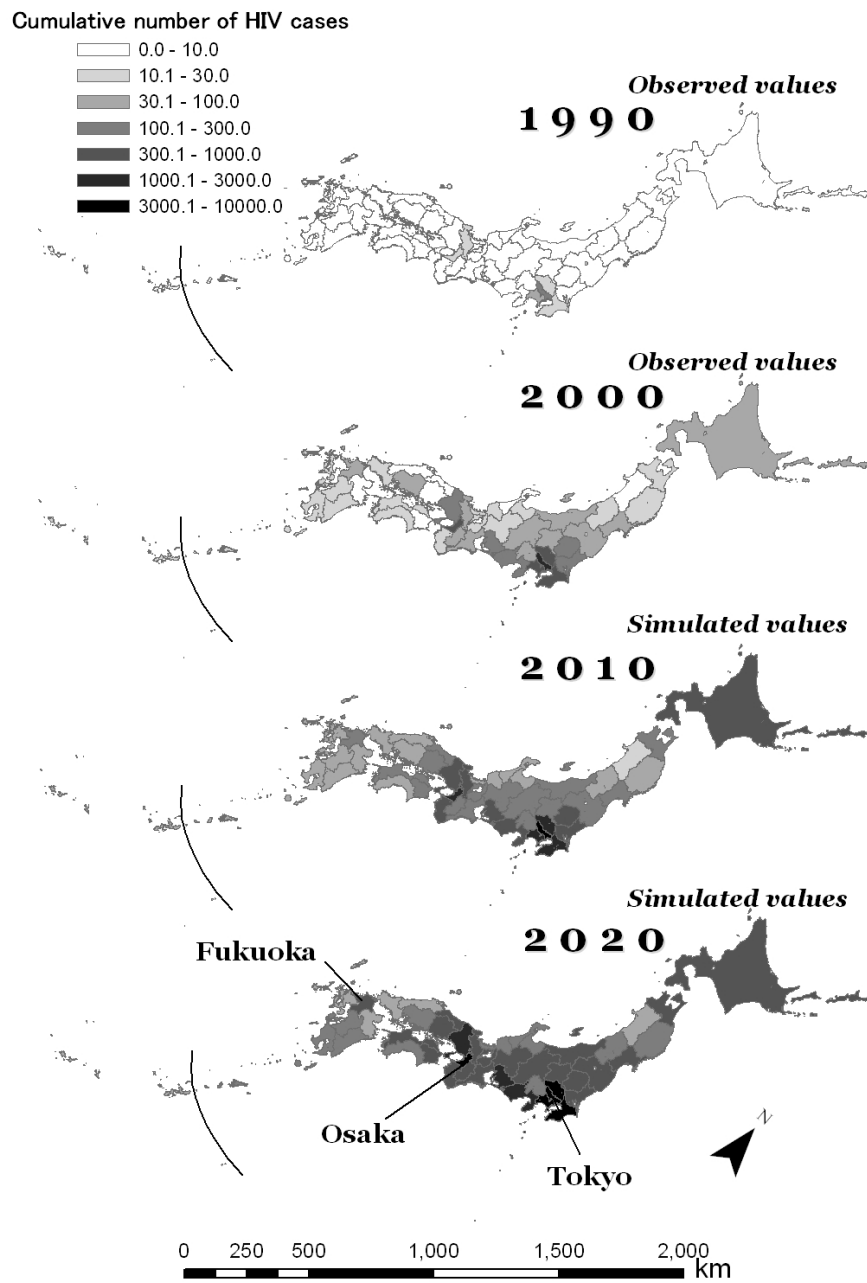


Figure 1: Spatial diffusion of HIV cases in Japan (spatio-temporal series of cumulative HIV cases)

Note: the numbers of cases are 2.4 times larger than those of surveillance reporting cases.

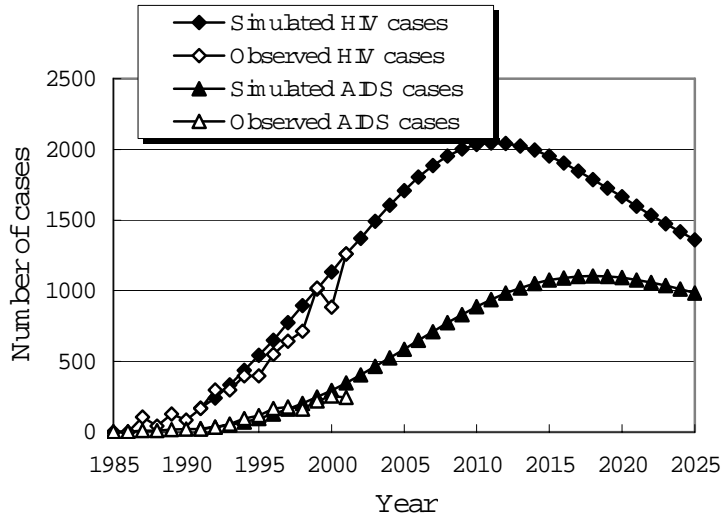


Figure 2: Newly reported HIV/AIDS cases (simulated and observed values) in Japan until 2025

Note: the numbers of cases are 2.4 times larger than those of surveillance reporting cases.

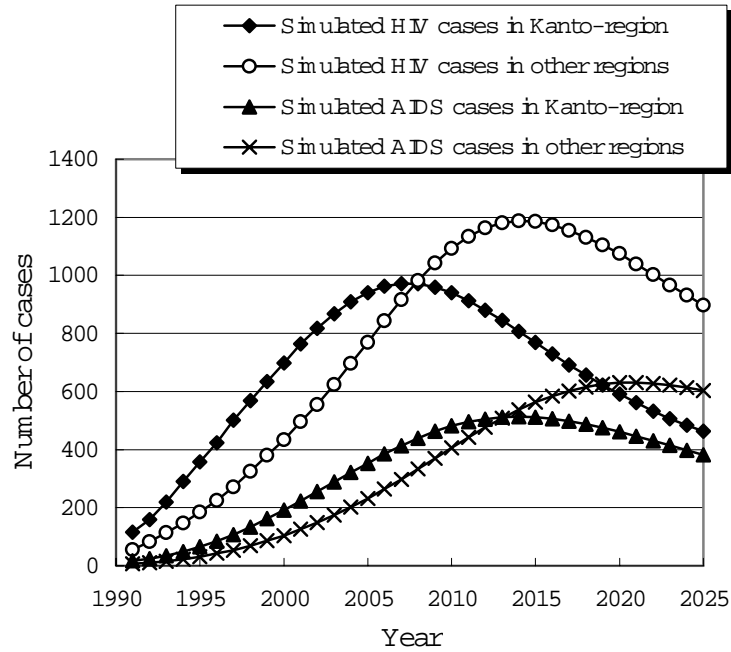


Figure 3: Regional trend of newly reported HIV/AIDS cases (simulated values) until 2025

Note: the numbers of cases are 2.4 times larger than those of surveillance reporting cases.

4.0 CONCLUSIONS

Through a geographical analysis of HIV/AIDS, we confirmed and predicted significant geographical variations in the HIV epidemic in Japan at a local level. Although the model result we employed here is based on many assumptions, it should be valuable for educational promotion and assembling our knowledge of geographical aspects of HIV/AIDS diffusion. It should be also helpful for assessment/planning of the clinical resources for HIV/AIDS test/treatment in terms of supply-demand relationships.

Our summary of the surveillance data and the model's results indicated that in peripheral areas the present size of the HIV/AIDS infection was small, and intervention actions preventing infection outside the areas were effective to control the spatial diffusion of HIV/AIDS in Japan. If we leave this state as it is, a significant rise in the number of cases will occur in peripheral areas as well as the Tokyo metropolitan area. We should take note of the spatial movement of high-risk populations visiting foreign countries and/or the major metropolitan areas in Japan.

Some improvements in the present reporting system are needed to verify and advance our understanding of the spatial movements of HIV cases/risk population. In particular, it is highly desirable that the HIV/AIDS surveillance system records the place of residence of patients and the estimated place of acquired infection by prefecture in order to enhance the utility of the surveillance system.

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