Sexuality-based compartmental model of spread of HIV in the Philippines

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Acquired Immunodeficiency Syndrome, (AIDS) a disease caused by the Human Immunodeficiency Virus (HIV), is a sexually transmitted disease that first started spreading worldwide in the 1980s. As of today, there is no known cure and, as a result, prevention and public awareness are paramount in controlling HIV infection. The Philippines has historically had one of the fewest cases of HIV. However, data have shown an alarming increase in sexually transmitted HIV infections over the past few years. In this study, the spread of HIV among the heterosexual, bisexual and homosexual groups was modeled using a compartmental Susceptible-Infectious (SI) epidemic model. The results showed a significant increase in HIV infections among bisexual and homosexual groups in the Philippines since 2006.

INTRODUCTION

The Human Immunodeficiency Virus or HIV first infected humans in the early 1980s. The disease has since become a pandemic of a global scale. Transmission of HIV primarily occurs via sexual contact or blood transfusion. Unlike other diseases which do not differentiate between victims, HIV transmission is limited to people who have the potential to acquire HIV either by: profession, such as sex workers; age group; social class; heredity, such as mother to child transmissions; lifestyle, which includes drug users, customers in the sex industry and those who have multiple sex partners; or misfortune, for example those who acquired it by blood transfer (Rao et al. 2009).

Upon infection with HIV, the virus begins to replicate itself at the cost of the body's CD4 cells. This stage is called acute infection, also known as primary HIV infection, or Acute Retroviral Syndrome (ARS). Symptoms include fever, chills, night sweats, muscle aches, sore throat, fatigue, rashes, swollen lymph nodes and ulcers in the mouth. This occurs 2-4 weeks after exposure to the HIV virus, but could take up to a few months, and, in some cases, the person never develops ARS. After ARS, the level of HIV stabilizes and the number of CD4 cells increase again. In this stage, called asymptomatic HIV, the infected person does not display any symptoms, but is still infectious. This stage may last 8 years or longer, depending on many factors, and may be prolonged with the use of medicine. Eventually, the CD4 levels become critically low and the person is said to have AIDS (aids.gov 2009). At this stage, the immune system has become severely damaged, causing the body to become susceptible to other diseases. The life expectancy of an AIDS patient is 1 to 3 years (Jacquez et al. 1988).

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Table 1. Percentage of each gender-age group at risk of HIV infection.

At risk	0-14	15-24	25-54	55-64	65-up	0-up
Male	0.23%	35.12%	54.06%	7.43%	3.39%	27.26%
Female	0.19%	4.54%	7.86%	1.24%	0.42%	3.88%

Population at risk by gender and age group, given as a percentage of each gender-age group, for the period 1985–2013. The values were projected by assuming a minimum of 1% of females were at risk for the period 2008–2013.

In the Philippines, the first HIV cases were recorded in 1984 when two people died due to AIDS. Although the number of cases has since grown, the Philippines remains one of the countries where HIV is not as widespread. According to data from the Department of Health, as of 2013, 11,349, just a little over 0.01% of the adult population in the Philippines, have been infected with HIV. Less than 10% of the infected have AIDS (doh.gov.ph 2013). However, the increase in sexually transmitted HIV infections in recent years poses an alarming threat. The data suggest that much of the increase is due to infections among the homosexual and bisexual groups. A mathematical model is needed in order to obtain a numerical description of these trends and to make forecasts. Currently, there is no known cure for HIV and the best way to eradicate the disease is to prevent new infections, or at the least limit them.

METHODS

Assume that the population at risk N is a fixed percentage of the entire population Ω, i.e. $N = a\Omega$, where $0 < a \leq 1$. A standard model used for diseases with no recovery is the Susceptible-Infectious or SI model (Akpa and Oyejola 2010). Let S be the number of people in the susceptible group and I in the infected group. Then

$$N = S + I. \tag{1}$$

The SI model is given by the following differential equations:

$$\frac{dS}{dt} = -k\frac{S}{N}I, \qquad \frac{dI}{dt} = k\frac{S}{N}I \tag{2}$$

where k is the rate of infection. Most pandemics and epidemics spread and die out over a relatively short period of time (possibly to reoccur later), thus (2) is typically modeled using a constant N. HIV infection, however, has been shown to persist continuously over time, hence the fixed population assumption is inaccurate. For example, the Philippine population has nearly doubled over a 28-year period. Let b be the population net growth rate (births less deaths) and assume the population at risk N increased at the same rate. Then

$$\frac{dN}{dt} = bN \tag{3}$$

From (1) and (3),

$$\frac{dI}{dt} + \frac{dS}{dt} = bN \tag{4}$$

An SI model with population growth (Lopez-Cruz 2006) can be written as

$$\frac{dS}{dt} = b(S+I) - k\frac{S}{S+I}I, \quad \frac{dI}{dt} = k\frac{S}{S+I}I - \mu I \tag{5}$$

The assumption is births increased the susceptible group S but not the infected group I, i.e. mother-child transmissions are not considered. The change in I is due to new infections, and deaths caused by the disease, its rate denoted by μ.

Consider an SI model with compartments according to sexual orientation, where the subscript H denotes the heterosexual group, B denotes the bisexual group and G denotes the homosexual group. Then $N = S_H + I_H + S_B + I_B + S_G + I_G$. The system of ordinary differential equations, which models interactions between the three sexuality groups, is now given by

$$\frac{dS_H}{dt} = b(S_H + I_H) - c_1\frac{S_H}{S_H+I_H}I_H - c_2\frac{S_H}{S_H+I_H}I_B - c_3\frac{S_H}{S_H+I_H}I_G$$

$$\frac{dI_H}{dt} = c_1\frac{S_H}{S_H+I_H}I_H + c_2\frac{S_H}{S_H+I_H}I_B + c_3\frac{S_H}{S_H+I_H}I_G - \mu I_H$$

$$\frac{dS_B}{dt} = b(S_B + I_B) - c_4\frac{S_B}{S_B+I_B}I_H - c_5\frac{S_B}{S_B+I_B}I_B - c_6\frac{S_B}{S_B+I_B}I_G$$

$$\frac{dI_B}{dt} = c_4\frac{S_B}{S_B+I_B}I_H + c_5\frac{S_B}{S_B+I_B}I_B + c_6\frac{S_B}{S_B+I_B}I_G - \mu I_B$$

$$\frac{dS_G}{dt} = b(S_G + I_G) - c_7\frac{S_G}{S_H+I_H}I_H - c_8\frac{S_G}{S_G+I_G}I_B - c_9\frac{S_G}{S_G+I_G}I_G$$

$$\frac{dI_G}{dt} = c_7\frac{S_G}{S_H+I_H}I_H + c_8\frac{S_G}{S_G+I_G}I_B + c_9\frac{S_G}{S_G+I_G}I_G - \mu I_G \tag{6}$$

The parameters c_i represent transmission rates between the various groups: c_1 is the rate at which heterosexuals with HIV infect heterosexuals; c_2 is the rate at which bisexuals with HIV infect heterosexuals, etc.

RESULTS AND DISCUSSION

According to Philippine demographic data, the 2012 population of 103.76 million was composed of the following age distributions: 19.1% were ages 15 to 24, 36.6% were ages 25 to 54, and 5.6% were ages 55 to 64. Males comprised 50.07% of the population, almost exactly half (The World Factbook 2013-

Table 2. Best-fit HIV infection rates.

Year	c_1	$c_2 = c_4$	c_5	$c_6 = c_8$	c_9
1987-93	0.28	0.02	0.04	0.04	0.37
1994-99	0.20	0.01	0.03	0.02	0.21
2000-05	0.12	0.005	0.01	0.01	0.12
2006-12	0.10	0.02	0.14	0.14	0.28

Infection rates over 5-6 year periods, obtained by best-fit for the compartmental model. The infection rates denote interactions between: c_1 – heterosexuals; c_2 – heterosexual and bisexual; c_5 – bisexuals; c_6 – bisexual and homosexual; c_9 – homosexuals.

14). Data on HIV cases obtained from the Philippine Department of Health showed that over a 28-year period from 1985 to 2012, the total number of asymptomatic cases was 10,534 and the total number of AIDS cases was 1,168, and the total deaths due to AIDS was 353 (doh.gov.ph 2013). Using regression, the annual death rate of AIDS patients was calculated to be 0.026. The mortality rate of people with HIV was $\mu = 0.0021$.

Over the period from January 1985 to May 2013, the total number of males with HIV was 11,802. The number of female cases over the same period was 1677, for a ratio of 7:1. To determine the population at risk, N, note that the minimum number of females at risk was around 1% of the population, which was the estimated number of females in the sex industry in the Philippines (McTavish 2010). Based on data from 2008 to 2013, the male-female ratio was 14.5:1. By projecting the numbers to 1% of the female population, the total cases were projected to be around 16% of the entire population. Using the same projections on the entire data from 1985 to 2013, we obtained proportions of each age group that were at risk of HIV. These values are presented in Table 1.

The values in Table 1 are reasonable. For example, according to the table, more than 1/2 of males aged 25 to 54 were at risk, and about 1/3 of males aged 15 to 24 were at risk. In contrast, about 1/12 of females aged 25 to 54 were at risk. Over their entire age group, more than 1/4 of males were at risk, which was acceptable considering that 15% of males in the Philippines reportedly frequented brothels (Balgos 2003). Less than 1/25 of females were at risk, and this number represented less than 2% of the entire population. The overall population at risk was 16% of the entire population, i.e. $N = 0.16\Omega$. The upper bound based on Table 1 was 30% of the Philippine population.

The initial population Ω_0 = 55.129 million in 1985 was calculated using interpolated data. The corresponding population growth rate was $b = 0.021731$. There were no available data for the number of homosexuals in the Philippines. This figure was difficult to obtain in other countries because some people who did not identify as homosexual or bisexual have had same sex encounters or fantasies. Most women identified as bisexual rather than homosexual, whereas men usually identified as homosexual rather than bisexual. Survey results in the USA suggested a range of 2% to 13%, with a nearly uniform split (Gates 2011). For the Philippines, the values were assumed to be 5% of the population for homosexuals, and 3% for bisexuals. Any heterosexual who had sexual interaction with a homosexual was automatically reclassified as bisexual, thus we can assume that the infection rate between heterosexuals and homosexuals $c_3 = c_7 = 0$. By symmetry, the infection rates between heterosexuals and bisexuals and vice versa should be equal, likewise for homosexuals and bisexuals, thus $c_2 = c_4$, and $c_6 = c_8$. This reduced the number of independent parameters to five.

Infection rates likely varied over time, depending on numerous factors, for example the generational culture, awareness, and random variations. Over shorter periods of time, changes in infection rates were possibly negligible. A partitioning of the HIV data was obtained by first plotting the logarithm of the HIV incidence values. The SI model indicated that initial growth of the I-variable would be nearly exponential. By using sections of data that were nearly log-linear, the following partitions were obtained: 1987-1993, 1994-1999, 2000-2005, and 2006-2012 (Gomez 2013). The sizes of the intervals turned out to be nearly uniform. The first three years of HIV infection, from 1984 to 1986, were excluded because the number of cases was too small and the values did not fit with the rest of the data.

Table 2 shows the parameter values obtained by best fit with the compartmental model (6). Infection rates among heterosexuals started high at 0.28, or roughly 2 new infections for every 7 infected heterosexuals, but steadily decreased over the years, to just 0.1 for the period 2006-12, or around 1 new infection for every 10 infected. Infection rates among homosexuals also started high at 0.37, decreased until 2005, but saw an increase to 0.28 for the latest period 2006-12. Infection rates among bisexuals started off low at 0.04 (1 new infection for every 25 infected) and decreased until 2005, but rose significantly in the last period to 0.14 (1 new infection for every 7 infected). Infection rates between homosexuals and bisexuals have also increased dramatically since 2006 to 0.14.

Figure 1 shows a plot of the data for sexually transmitted HIV cases based on the infection rates in Table 2. The data on AIDS deaths did not identify the sexuality of the patient, and thus the values were prorated among the three groups. The parameters in the last time period 2006-12 were used to forecast the number of HIV cases in the Philippines until 2020. The extrapolations suggested that if current patterns in HIV infection do not change, the number of homosexuals with HIV in the Philippines in 2020 will be around 75,000, the number of bisexuals will be over 40,000, and the number of heterosexuals will be a little more than 10,000. The projected total in 2020 was still less than 1% of the population; however, the significant increase particularly with

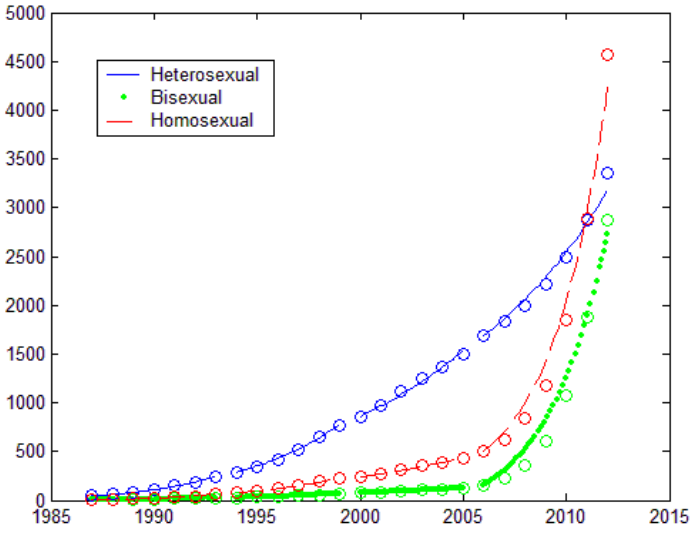

Figure 1. Best fit using compartmental model versus actual data for the three sexuality groups. Plot of the number of cases of HIV for the heterosexual (blue), bisexual (green) and homosexual (red) groups for the years 1987-2012. Circles are actual data, while lines are interpolations using the compartmental model. Partitions in the data are 1987-93, 1994-99, 2000-05, 2006-12.

respect to the bisexual and homosexual groups would make it more difficult for the disease to be contained in the Philippines.

CONCLUSION

The Philippines continues to have one of the fewest incidences of HIV infection. One explanation is that Filipinos are generally more conservative, and thus have fewer sexual partners over their lives. Another reason is a smaller percentage of Filipino males frequent brothels as compared to males from other countries. It is also possible that the number of reported cases of HIV is much less than the actual number, especially since Filipinos are more easily embarrassed and tend to be more discreet about contracted diseases. Nevertheless, until there is evidence that says otherwise, we can only assume the data from the Department of Health is honest and representative of the actual number of cases. According to the data, the number of males with HIV outnumbered the females by 14.5:1 over the past 5 years. Because female prostitutes are always at risk, and these constituted at least 1% of the population, this was used as a lower bound for estimating population at risk. Projections based on these proportions suggested that 16% of the Philippine population is at risk of HIV, although this number could be as high as 30%. The annual mortality rate of AIDS patients was computed to be 1 in 40, much lower than in other countries.

A compartmental model of spread of HIV was used to determine infection rates among groups within the population at risk. The model compartmentalized the population according to the three sexual orientations given by Department of Health data: heterosexual, homosexual and bisexual. In many studies and surveys, bisexuals and homosexuals are grouped together, and a case can be made for a compartmental model with two compartments: heterosexual and non-heterosexual. However, this method would present problems in reclassifying those that were considered bisexual in the data. For example, a male identified as bisexual may be primarily heterosexual but services homosexuals in the sex industry. Alternatively, a female identified as bisexual may be primarily homosexual but services heterosexual males.

One limitation of the study is the lack of demographic information regarding the ratio of homosexuals and bisexuals in the Philippines. The values assumed in the study were 5% and 3% of the population, respectively. Fortunately, these assumptions, although reasonable in the context of similar demographic studies of sexuality in other countries, do not significantly affect the results. However, it is important to obtain sexuality-based demographic data in the Philippines for future and related studies.

A more complete model would include age compartments in addition to sexual orientation. Unfortunately, Philippine Department of Health data only have yearly breakdowns in age starting in 2008. As more data become available, future studies should be able to include age compartments in their models.

The results showed that infection rates among heterosexuals have decreased since 1984. Public awareness, such as the AIDS awareness campaign of the Department of Health, and changes in sexual habits were largely effective for this group. However, the results also showed that despite decreasing from 1984 to 2005, infection rates among homosexuals and among bisexuals have increased for the period 2006-12. These recent changes may be due to the country becoming more accepting of homosexuality in recent years, as well as an increase in the number of homosexuals and bisexuals. There also may have been a corresponding increase in the number of homosexual prostitutes. Moreover, an increase in number of openly homosexual people may have resulted in a corresponding increase in number of workers in the sex industry who service individuals with a different orientation, for example the heterosexual male who serviced homosexual male clients as mentioned previously. It is also possible that more individuals in today's environment readily self-identified as bisexual rather than homosexual or heterosexual.

Forecasts based on current trends showed that in 2020, the number of infected heterosexuals will have increased by 200%, but the number of infected bisexuals will be up 1,300% and the number of infected homosexuals will have gained by 1,500%. Government policy and support from social groups are needed in bringing public awareness and effect changes in the sexual habits of homosexual and bisexual groups, who are at high risk of infection of HIV. The AIDS awareness campaign by the Department of Health that was effective for heterosexuals may be targeted towards homosexuals and bisexuals. Such measures

would help reverse recent trends and control the spread of HIV in the Philippines.

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CONFLICTS OF INTEREST

There are no conflicts of interest.

CONTRIBUTIONS OF INDIVIDUAL AUTHORS

Much of the work was from the undergraduate thesis of F. Gomez, who collected the data, did background research, helped prepare the model, and conducted numerical simulations. G. David served as her thesis adviser, came up with the ideas for the model, helped with the numerical method, and prepared the journal manuscript.

REFERENCES:

AIDS.gov. Stages of HIV. Last revised: 08/06/2009, accessed on November 4, 2013.

Akpa OM, Oyejola BA. Modeling the transmission dynamics of HIV/AIDS epidemics: an introduction and a review. J Infect Dev Ctries 2010; 4(10):597-608.

Balgos C. Philippines proud of its low infection rate, number of cases. San Francisco Chronicle, May 21, 2003.

Doh.gov.ph. Newly Diagnosed HIV Cases in the Philippines, 2013. Retrieved from http://www.doh.gov.ph/disease-surveillance.html, accessed on Sept 27, 2013.

Gates GJ. How many people are lesbian, gay, bisexual, and transgender? The Williams Institute, UCLA, 2011:1-11.

Gomez F. Cross-compartmental epidemic model of spread of HIV in the Philippines. Undergraduate Research Paper, University of the Philippines 2013.

Jacquez JA, Simon CP, Koopman J, Sattenspiel L, Perry T. Modeling and analyzing HIV transmission: the effect of contact patterns. Mathematical Biosciences 1988; 92:119-199.

Lopez-Cruz R. Structured SI epidemic models with applications to HIV epidemic. Ph.D. Dissertation, Arizona State University, 2006.

McTavish J. Prostitution in the Philippines: a time for change. Landas Loyola Journal of Theology 2010; 24(1):121-135.

Rao AS, Thomas K, Sudhakar K, Maini PK. HIV/AIDS epidemic in India and predicting the impact of the national response: mathematical modeling and analysis. Mathematical Biosciences and Engineering 2009; 6(4):779-813.

The World Factbook 2013-14. Washington, DC: Central Intelligence Agency, 2013. Retrieved from https://www.cia.gov/library/publications/the-world-factbook/index.html