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A Statistical Model and Analysis on Mobility and the Spread of Human Immunodeficiency Virus (HIV) in the Plateau (Nigeria Case Study)

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Abstract: Research reports show that about 70% of all those with HIV (AIDS) world wide live there. As fight against HIV (AIDS) increase worldwide, it is noteworthy that global number of people living with HIV continues to rise. In this study, a statistical model here describes the association between HIV infection mobility/spread and the predictor variables. The Strength of association between were summarized using Odd Ratios (OR) and corresponding 95% Confidence Interval (CI). Secondary data was collected from HIV Testing Centres in Jos and descriptive statistics of the sample were obtained through frequencies and cross tabulations. STATA was used for data analysis and to evaluate the values of the parameters a multivariate logistic regression model was formulated using the multiple-factors of HIV/AIDS prevalence among sex Age and marital Status.

Key words: HIV infection, mobility, statistical model, odd ratio, multivariate logistic regression

INTRODUCTION

Labour migration played a critical role in the spread of HIV and so is the climatic condition do promote the mobility of the AIDS virus as sexual activities is more prevalent in relatively cold weather than during hot seasons (Colvin and Sharp, 2000). This duo informed the choice of the research case study, Jos Plateau in North-Eastern Nigeria. Jos Plateau is the capital city of Plateau State in Nigeria with a population of about 0.5 million the 10th largest city in Nigeria. Jos has become an important national administrative and commercial centre. Tin mining has led to the influx of migrants, mostly Hausas, Igbos, Yorubas and Europeans who constitute more than half of the population of Jos. This melting pot of race, tribe and religion makes Jos one of the most cosmopolitan cities in Nigeria. For this reason, Plateau State is known in Nigeria as the home of peace and tourism (Wikipedia encyclopedia). The temperature ranges between-5°C (min) and 25°C (max). Jos is surrounded neighbouring states and cities where there is a very weak HIV surveillance due to religious restrictions, where polygamy is allowed and women are restricted to stay indoor but their male partners are allowed to go out and visit even the 6 workers. Mobility and local migrants, had been noted as one August 13, 2008 of the factors of easy transmission of HIV/AIDS in some parts of West Africa (Largarde *et al*., 2003). Likewise the proximity to Abuja, the federal capital city of Nigeria makes it possible for migrants from all parts of Nigeria both good and bad to flock Jos city thus, contributing immensely to the spread of HIV infection in this city.

Mathematical and statistical models: For the past several decades mathematical principles have had an important role in disease control strategies (Boily *et al*., 2002) and will continue to do so in future. Application of the models becomes easier if there are sufficiently accurate data for the variables used and the concerned parameter values. Kermack and McKendrick's treatment of the Bombay plague of 1905-1906 proved the capability of mathematical models in understanding and predicting epidemics (Kermack and McKendrick, 1927). Anderson and May (1992) present more models of infections including HIV with illustrations. Models of HIV spread specific to the type of transmission have also appeared in the literature for homosexuals (Anderson and May, 1988) and for heterosexuals (Anderson and May, 1988; Kakehashi, 1998).

The first case of HIV/AIDS infection was diagnosed in Nigeria over 2 decades ago. Initially the spread of HIV did not attract much attention until in the early nineties when there was a noticeable media exposure or systematic surveillance. As at the end of 2005, the HIV prevalence estimate in Nigeria stands at about 6.3 million people, which doubles the population of Namibia and Botswana (both Southern African countries). Plateau State was identified as one of the worst affected in Nigeria.

There is a lot of information on HIV viral dynamics all over the world now. Despite an identification of major risk groups and their behaviours, the picture of the dynamics of HIV spread in Nigeria is not still very clear. This is primarily due to, the absence of scientific means of gathering and modeling information on the infectious period of HIV infected, time to the onset of AIDS, sexual behaviour of high risk and low risk individuals in the population, probability of transmission from the infected to the susceptible per partnership and other relevant parameters.

The unclear dynamics of HIV spread and the existing threat of the HIV/AIDS scourge in Nigeria are challenges that are posed to Applied Mathematical researches. These are a lot of public and international donor funds going into both awareness and management of infected persons in Nigeria.

In this research, an attempt was made to design a Statistical model from a set of Secondary data of about 500 tested persons.

Simple epidemic model: Consider an epidemic model in which, the population is closed comprising susceptibles, infectives and the recovered (Kermack and McKendrick, 1927). Recovered individuals are assumed not to contribute to the infection process. But since HIV infection is not curable, this model is not applicable to it. We can modify the model by replacing the recovered with the dead and still considering population as closed and is divisible into three groups, viz. X (susceptible, i.e., those at the risk of being infected with HIV), Y (infective, i.e., those who have HIV and can transmit it to X) and Z (the dead). If the population mixes homogeneously, then reduction in susceptible will become increase in infectives.

Infections occur at a rate proportional to the number of infectives and susceptibles, i.e., r_1XY, where r_1 is the proportionality constant. Infectives die at a rate proportional to the number of infectives, i.e., r_2Y, where r_2 is the proportionality constant. A new batch of infectives exits from the susceptible group and is added to the infective group at a given unit of time. The change in the number of infectives per unit of time will be the difference between newly turned infectives and deaths from infectives per the same unit of time. An ordinary differential equation can represent the instantaneous rate of change in each of the three variables X, Y and Z with respect to time t.

$$\frac{dX}{dt} = -r_1XY \quad (1)$$

$$\frac{dY}{dt} = r_1XY - r_2Y \quad (2)$$

$$\frac{dZ}{dt} = r_2Y \quad (3)$$

The above model, does not consider advanced stage of HIV, i.e., AIDS. Our next model takes account of AIDS cases, but not the number of the dead. Suppose that C is the average number of sexual partners per unit time and b is the probability of transmission from infective to susceptible per partnership. Then the per capita force of infection is bCXY/N, where Y/N is the probability that the sexual partner is infective. R0 = bC/day is known as basic reproductive rate of infection, where d is the rate of infectives moving into the AIDS group and 1/day is the average duration from infection to AIDS. Patients die at a rate m per unit of time. In the early stage of an epidemic, almost all the individuals in the population are susceptible, i.e., X ≅ N; doubling time, td defined as the time taken for the doubling of the infected number can be calculated.

$$\frac{dX}{dt} = \frac{\beta CXY}{N_1} \quad (4)$$

$$\frac{dY}{dt} = \frac{\beta CXY}{N_1} - \delta y \quad (5)$$

$$\frac{dA}{dt} = \delta Y - \mu A \quad (6)$$

$$t_d = \frac{1}{\delta(R_0 - 1)} Ln(2) \quad (7)$$

In the case of Nigerian HIV epidemiology, there are only indirect estimates of incubation period and data on the 2 parameters (doubling time and basic reproductive rate) discussed in the above paragraph are not available. Initial doubling time in Nigeria cannot be calculated in the absence of accurate HIV figures in the beginning of the epidemic. Current estimates of HIV cases in Nigeria, are high probably because the basic reproductive rate is greater than 1 in the early stage of the epidemic.

Numerical examples:

- If $R_0>1$, then the epidemic is said to be growing.
- If $R_0<1$ then the epidemic is said to be diminishing.

Assume that R_0 = 1.034 (i.e., just above 1) and the incubation period is 10 years. Then the doubling time will be 2 years, which indicates a slow spread in the early stage. A small increase in basic reproductive rate results in the reduction of the doubling time to half of its previous value, e.g., if $R_0 = 1.069$ and incubation period 10 years, then the doubling time will be only 1 year.

- Model Eq. (4)-(6) can be numerically explored for suitable parameters. If b = 0.02, C = 25, d = 0.1 and m = 1, then the changes in the number of individuals over time will be depicted.

Taking b = 0.04 and keeping all the parameter values as earlier, the situation changes An increase in b can be observed in terms of faster growth in infective group as well as earlier peaking, by about 6 years and both of the infective and AIDS groups. The probability of transmission is a key parameter in the course of the epidemic when all other values remain constant.

These values may not be representative of the true epidemic and behavioral patterns in Nigeria.

HIV transmission model (heterogeneous mix): In the earlier model, we assume homogeneous mixing between susceptible and infective, the same probability of an infective transmitting virus to a susceptible and no factor that inhibits sex between infective and susceptible.

To make the model realistic with respect to the behavioural changes and transmission probabilities, we need to introduce more complexity. Earlier researchers have proposed models of heterosexual behaviour (Kakehashi, 1998).

The model presented here was based on the prevention of transmission to and from FSWs with heterogeneous mixing. It explains mechanisms of transmission of virus from FSW to adult males and vice versa.

Let, us divide the male population that mixes with FSWs into 4 classes: Male susceptible, HIV infective, STD infective and both STD and HIV infective. For the purpose of this research, the rates of additions of male susceptibles from non-susceptible and STD cured are taken to be exponential. These rates in reality may be different. At the same time the numbers of individuals infected with HIV and STD per unit of time and the number who withdraw from risk behaviour are removed from the susceptibles. The withdrawal number is based on general withdrawal rate, or dependent on individual behaviour. In the case of males, new HIV (STD) infective population is determined from the following: Proportion of susceptibles and HIV (STD) infected FSW population to the total FSW population, the number of partnerships per unit of time, the probability of transmission of HIV (STD) from an infected FSW per partnership.

After being HIV positive, one can still be STD infective and vice versa. Such, individuals are called dual infected, i.e., with both HIV and STD. Dual-infected individuals who recover from STDs remain as HIV infective.

Other withdrawal cases, e.g., natural deaths, change of risk behaviour, etc. either from HIV (STD) infective or from dual infected, can be removed from respective compartments.

$$\frac{dX_0}{dt} = \lambda_m - (F_{10} + F_{20} + \mu_m)X_0 + \gamma_m X_2 \tag{8}$$

$$\frac{dX_1}{dt} = F_{10}X_0 - (\mu_m + \delta_1 + F_{21})\ X_1 + \gamma^1{}_m\ X_3 \tag{9}$$

$$\frac{dX_2}{dt} = F_{20}X_0 - (\mu_m + \delta_2 + F_{12})\ X_2 - \gamma_m\ X_2 \tag{10}$$

$$\frac{dX_3}{dt} = F_{21}X_2 - (\mu_m + \delta_1 + \delta_2)\ X_3 - \gamma^1{}_m\ X_3 \tag{11}$$

Similarly, we can formulate Eq. for Female 6 Workers. The probabilities of transmission are not available for Nigerian heterosexuals. (Tan Wai-Yuan, 2000; Brookmeyer, 1994).

Mobility factors in the transmission of HIV: Introducing geographical parameters, e.g., urban and rural bases, different states, etc. in the model with a view of predicting new HIV and AIDS cases specific to them are certainly useful. It is not difficult to incorporate variations such as behavioral changes, condom usage and features like immigration rate in the model and corresponding software for predictions. Besides, since incubation period of AIDS is dependent on the age at the time of infection some models incorporated that factor in their projections. Though, male-female behavioral patterns might change with increasing age, incubation period is not gender-biased. These factors need to be incorporated, while modeling age-specific impact of HIV/AIDS in Nigeria.

MATERIALS AND METHODS

The Study location is Jos, Plateau in North Eastern Nigeria, which hosts the local dwellers migrants from both neighbouring regions (the Northern part of Nigeria, Chad Republic and Northern Cameroun) and some other expatriates. Free movement from the Federal Capital City, Abuja also forms a major factor of mobility effect in Jos.

Procedure for data analysis: The research instrument used in this research work is documentary method. This entails going through existing record of HIV/AIDS cases. The random sampling was employed to select the hospital from the population of study (Jos metropolis).

The data collected was from July, 2004 to June 2007 and were presented and itemized according to patients responses, sought in the patient's folders. In analyzing the data; the simple percentage method and cross tabulation method was used to make comparison with the responses derived. The basic statistical technique employed for hypothesis testing and model building was logistic regression and stepwise regression procedures.

The prevalence of HIV in each category of the predictor variables was determined and the association between HIV infection and predictor variable were summarized by using Odd Ratios (OR) and corresponding 95% Confidence Intervals (CI). To adjust for multiple risk factors simultaneously, multivariate analyses were performed by using logistics regression models. All significant variables in the univariate analyses ($p<0.05$) and others that were thought to be important based on previous reports were included in a list of candidate variables for multivariate logistic regression models. Stepwise procedures, using both forward selection and backward elimination procedures, were used to determine the final logistic regression model.

Logistic regression is appropriate for binary response variables or for modeling the risk of prevalence of disease. When, fitting statistical models for risk or prevalence studies, the log odds of diseases is commonly used as the measures of disease outcome, the reasons for modeling the log odds rather than the proportions is that the log odd can take any value, positive or negative, whereas proportions are constrained to lie between 0 and 1.

Most testing centres do not keep records of the needed parameters, some data were not comprehensive enough, while some containing very personal details were not made available. Thus, only 484 persons had adequate records for the purpose of this study.

RESULTS AND DISCUSSION

In this research, social-economic and demographic characteristics taken into consideration include age, sex, marital status and HIV status. In Table 1 shows the details of the presentation of raw data.

Model specification and hypothesis testing: Here we use the logistic regression formulae for the modeling of the spread of HIV among the risk factor parameters:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + e_{rr}$$

Where:

x_1 = Gender.
x_2 = Age.
x_3 = Marital status.
β_0 = Intercept of the logistic regression line.
$\beta_1, \beta_2, \beta_3$ = The logistic regression coefficients of the independent variables x_1, x_2, x_3, respectively.
e_{rr} = The residual/error term.
Y = The rate of HIV/AIDS infection.

Test for the relationship between HIV/Aids and sex: Using the data in Table 1 and the Statistical package STATA for analysis we test for the relationship between the spread of HIV and Gender in the Plateau.

$$H_0: \beta_i = 0$$

H_1 = β_i is significantly different from zero.
α = 5%, the test probability $p>0.05$.

We therefore, accept the null hypothesis that B1 is not significantly different from zero.

Hypothesis testing of the adequacy of fitted model:

$$H_0: \beta_i = 0$$

H_1 = $\beta_{i's}$ are significantly different from zero.
α = Five percent the test probability $p>0.05$.

We therefore, accept the null hypothesis that B_i^s is not significantly different from zero. There is a highly statistical significant association between sex, age and marital status and the odds of HIV/AIDS infection.

The STATA output shows the estimated parameters and hence, the fitted model for HIV/AIDS infection is given as:

$$Y = -0.0413386 + 1.1013843x_1 - 0.087392x_2 + 0.199595x_3 + e_{rr}$$

We present here the study to use comparative standardized data from the settings to show the effect of climatic conditions and mobility as important factors responsible for the spread of HIV/AIDS among the people of the Plateau in Nigeria.

The ubiquity of mobility and climate means that they cannot explain why HIV is high among the different groups of people considered residing or transiting through Jos Plateau, but they are clear risk factors as they associate with the other risk factors.

Table 1: Univariate analysis of risk factors for HIV infection in Jos City, Plateau State

	Men				Women			
	HIV positive	HIV negative	Total	HIV positive (%)	HIV positive	HIV negative	Total	HIV Positive (%)
Age group								
<15 Years	10	4	14	71.43	10	9	19	52.63
15-29 Years	30	26	56	53.57	119	25	144	82.64
30-49 Years	62	33	95	65.26	114	24	138	82.61
≥50 Years	7	3	10	70.00	6	2	8	75.00
Sex	104	70	174	59.77	249	61	310	80.32
Marital status								
Married	57	36	93	61.29	156	24	180	86.67
Never married	37	28	65	56.92	60	32	92	65.22
Divorced/separated	1	2	3	33.33	17	3	20	85.00
Widowed	5	4	9	55.56	20	2	22	90.91

Table 2: Results from the analysis of relationship between HIV/Aids and gender

	Odd ratio	SE =RFC Mean±SD	Z	p>I Z I	(Conf. Interval at α =0.05)	
Sexcode 1	2.520458	0.5557483	4.79	0.000	1.63604	3.88298

Prob>[P] = 0.000. Since, p>[Z] is less than the level of significant (α = 0.05)

Table 3: Results from the analysis of relationship between HIV/Aids and all the risk factors

Risk-factor Codes	Coefficients	SE = Mean±SD	Z	p>|Z|	(Conf. Interval at)	
Sexcode	1.0138430	0.21437890	4.73	0.000	0.5936678	1.434018
Marstcod	-0.0873920	0.11533110	-0.76	0.449	-0.3134376	0.1386521
Age	0.1990595	0.09803750	2.03	0.042	0.0069095	0.3912094
-cons	-0.0413386	0.32003046	-0.13	0.897	-0.6691241	0.5864469

Prob>[P] = 0.000. Since, p>[P] is less than the level of significant (α = 0.05)

From Table 2, it is clear from the statistical analysis that there is a highly statistical significant association between sex and the odds of HIV/AIDS infection. The odd of female compared to male is 2.52, we therefore, conclude that more female are likely to be infected with HIV/AIDS compared to their male counterpart.

The STATA output in Table 3 helps us to fit the Statistical Univariate logistic model for the spread of HIV/AIDS within Jos Metropolis due to the associated risk factors considered that are peculiar to this settlement. In as much as these risk factors are left unchecked the infection rate of HIV/AIDS will keep growing at an alarming rate.

The residual/error term in the model excludes the effects of length of stay of mobile dwellers in Jos (i.e., the influx and out flux of people).

The relative high prevalence of HIV among people in Jos Metropolis indicates that this population is experiencing a generalized pandemic. The prevalence of HIV in this population was substantially higher than the average national prevalence. Result from the research indicates a substantial increase in the prevalence of HIV among people in Jos Metropolis between 2004 and 2007; (Table 1). This increase is a reflection of the rising trend of HIV infection in the general population and confirms that HIV is a major risk health problem in Nigeria.

The increased risk of HIV among relatively young women has been associated with increased biological vulnerability and untreated STDS. In addition, young women tend to have sexual relationship with relative older men who have been exposed to the risk of HIV for many years and exposure to multiple male partners. It is obvious from Table 1 that majority of the widowed persons have HIV infection. This is largely due to the fact that their late spouses died of the same infection.

The findings reveal that more females are infected with HIV/AIDS compared to their male counterparts. The greater efficiency of male to female transmission compared to female to male transmission is due to the relative infectivity of the semen and vaginal secretions.

HIV/AIDS retard economic growth thereby destroying human capital. About 51% of the people infected with HIV/AIDS are the young adults: this will result in a smaller skilled population and labour force leading to reduced productivity. With the consistent and correct use of condom, there is a very low risk of HIV infection.

RECOMMENDATIONS

Since, HIV/AIDS has no known cure medically, this research work will like to recommend the following as a way forward to reducing the spread of HIV/AIDS infection in the Plateau and other areas with climatic, social and geographical resemblance to Jos Plateau.

- The Government should pioneer approaches towards reducing stigma, bringing discussion of sexual behaviour out into the open, involving HIV infected people in public education, persuading individuals and couples to be tested and counseled, improving the status of women, involving religious organizations, enlisting traditional healers and much more; other programmes and initiatives to promote condom use like the CNN and ABC approaches.

- Medical workers should follow universal precautions or body substance isolation such as wearing latex gloves, when giving injections and washing the hands frequently to prevent infections of HIV.
- All AIDS prevention organization should discourage drug users from sharing needles and other materials required to prepare and take drugs and the use of properly sterilized needles should be encourage.

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