

Statistical Modelling Of HIV/Aids Epidemic In The North Central Zone Of Nigeria

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Abstract

The objective of this work were to apply the UNAIDS Estimation and Projection Package (EPP) to HIV/AIDS epidemic in the north central zone of Nigeria, to propose a statistical model for the course of the epidemic in the zone and to generally investigate the level of trend inherent in the epidemic, over the years. We used HIV/AIDS surveillance data to model the situation for the rural and urban sentinel sites in the zones. Using the EPP as our point of reference, we proposed a statistical model (based on modifications made to the original back calculation methods) for the course of HIV/AIDS epidemic in the zone. Our result shows that the UNAIDS package is a great AID to HIV/AIDS modeling in Nigeria. The incidence rate was estimated to be 0.91 in 1997, 0.7% in 2000 and projected to be 0.63 in 2010. Also an estimated 378,870 people are expected to die due to the epidemic in the year 2010. The prevalence peaked later than the incidence which peaked around 1997, but this is expected to rise slowly after 2007. The mortality rate is relatively low among sites inside major towns (IMT) than those outside major town (OMT), but the situation is generally still on the rise.

INTRODUCTION

HIV/AIDS epidemic is without doubt one of the most critical challenges facing public health in the world, particularly, Sub-Saharan African Countries. Africa with just over 10% of the world's population carries well above 75% of the burden of this epidemic (UNAIDS, 2004). Prevalence and Incidence rates in East Africa and South Africa include some of the highest in the world, with prevalence rates exceeding 35% in Botswana and Swaziland, but in the West African sub-region, prevalence rates have remained lower with no country having a rate above 10% and most having a rate between 1% and 5% (Nasidi and Tekena, 2004).

Since the first AIDS case was reported in Nigeria in 1986, the epidemic has grown steadily, with the adult HIV prevalence increasing from 1.8% to 5.8% in 2001, (FMOH, 2004). But, in the subsequent HIV/AIDS Sentinel Surveillance Survey (HSSS) conducted in 2003 and 2005, there was an evidence of decline; 2003-5.9% and 2005- 4.4 %, (FMOH, 2005) in the prevalence of the disease in Nigeria.

THE NEEDS FOR THE MODEL

Focusing on the epidemiology of HIV/AIDS in Nigeria, several studies have been published, (Tomori, 2004; Isiugo-Abanihe, 1994; Isiugo Abanihe, 1993; Nasidi & Harry,

2004; USAID, 2002; Canning et al, 2004a; Canning et al, 2004b), but virtually nothing has been done in the area of modeling the course of the infection overtime. Infectious disease data have two features that distinguished them from other data. They are highly dependent and the infection process is only partially observable (De Angelis, Day and Gill, 1998).

A consequence of these features is that the analysis of data is usually most effective when it is based on a model that describes aspects of the infection process Becker and Britton (1999). Again, an understanding of the magnitude and trajectory of the HIV/AIDS epidemic, as well as the uncertainty around the parameters is critically important both for planning and evaluating control strategies and for preparing for vaccine efficacy trials (Salomon, Gakidon & Murray, 2001). Mathematical models can become very useful tools in this area. Therefore modeling is an integral part of statistical work in HIV/AIDS research.

Apart from that, modeling exercise are aimed at making use of the available data (no matter how little) to provide information about the trend inherent in the course of the epidemic. Since in Nigeria, data on HIV/AIDS are scanty, a better insight can be provided if analysis of the data is based on estimate of statistical models whose assumption are

realistic and with parameters defined to capture the situations peculiar to the locality. One of such statistical models is the back-calculation method that was first proposed by Brookmeyer and Gail (1986) for estimating infection distribution and for providing short-term projection of future AIDS case (Tan, 2000).

Back-calculation is a method for estimating past infection rates from AIDS incidence data (Brookmeyer & Gail, 1994). The model has been used with some successes in several countries and situations (Brookmeyer & Damino, 1989; Brookmeyer & Liao, 1990, Brookmeyer 1991; Rosenberg, 1994 and Marion & Schecter, 1993). To apply the method to modeling work in sub-Saharan African countries, some modification has been introduced by Salomon and Murray (2001).

In this work, we proposed a generalized logistic model for the infection distribution of HIV/AIDS epidemic in the North Central Zone of Nigeria. We adopted the modifications made to the method of back-calculation as proposed by Salomon & Murray (2001). In section 2, we present details of the modifications and how we used it. Our results are presented in section 3 and in Section 4, we discussed our findings.

METHODS

SOURCES OF DATA

We made use of the data obtained from past HIV/AIDS Sentinel Surveillance Survey (HSSS) in the zone and published by the FMOH. The biannual HIV/AIDS Sentinel Surveillance Survey (HSSS) conducted by the Nigerian Federal Ministry of Health (FMOH) remains one of the most readily available strategies that provides information about the epidemic in the country as well as in the focused zone.

The Federal Ministry of Health through the department of public health, National AIDS/STI Control Programme, publishes biannual technical reports on the prevalence of HIV/AIDS in the various Sentinel sites (which are antenatal clinics – ANCs) in the six geopolitical zones of the country and data for each HSSS are made available in the Technical reports. It is believed that the data from the antenatal clinics most closely approximate prevalence levels in the adult population (Glys et al, 2005 and Salomon & Murray, 2001). In Nigeria, the Sentinel Surveillance Programme was based on the unlinked anonymous method, using the screening for Syphilis as entry point. All samples were stripped of identity, recorded by state, site, and age, properly stored and

sent for HIV testing with Capillus and Genie II kits as specified in the protocol. All results and samples were documented and forwarded to the National Reference Laboratory (NLA) in Abuja. The samples were subjected to quality control in NLA (FMOH, 2003).

The survey which is conducted every two years started in 1991 with a total of 16 sites which could not be divided into urban and rural. The most recent survey was conducted in 2005 with a total of 160 sites (86 urban-IMT and 74 rural-OMT), 30 of which originate from the North Central Zone (FMOH 2005). Although population based prevalence surveys would be the most useful, they have not been undertaken in Nigeria, due to cost and logistics.

At the earlier phase of the HSSS, sites, rather than being identified as urban and rural, were identified as major town (MT) and outside major town (OMT) respectively (FMOH, 2003), it is only in the 2005 HSSS that the former were used (FMOH, 2005).

THE MODELS

Salomon & Murray (2001) adapted a model for the incidence of HIV from the original back-calculation framework (equation 1) by focusing on HIV seroprevalence data, rather than AIDS notification.

AIDS diagnosis rate at time $t = \int_0^t (i(s) f(t-s)) ds$ (HIV infection rate at time s) \times Pr (incubation time $= t-s$) ds . Which is equivalent to

Figure 1

$$a(t) = \int_0^t i(s) f(t-s) ds. \tag{1}$$

Where $a(t)$ is the number of AIDS cases diagnosed at time t , $i(s)$ the infection rate at time s and $f(t)$ is the probability density function of the time from HIV infection to AIDS Diagnosis (the incubation period distribution, which are estimates from cohort studies of HIV- infected persons) and is assumed that this follows a Weibull distribution. (Salomon & Murray, 2001; Salomon, Gakidou & Murray, 2001; Nishiura et al, 2004; and Srinivasa Rao, 2003).

Therefore, if both the AIDS diagnosis rate and the incubation time distribution were known exactly, the underlying infection process could be reconstructed. The estimated infection process can then be used together with the incubation time distribution to predict future AIDS cases.

The basic idea of the original back-calculation is to use AIDS incidence data together with an estimate of the incubation period distribution to reconstruct the numbers of

individuals who must have been previously infected in order to give rise to the observed pattern of AIDS incidence (Brookmeyer & Gail, 1994). But AIDS Incidence data are practically difficult to come by in Nigeria. Consequently, the foundation of our model was the relationship between prevalence, incidence, and survivorship over time for infected individuals. The discrete form of equation (1) is given by:

Defining $t = 0$ as the first year of the epidemic, the number of HIV-infected individuals at time t is equal to the total number of individuals who were infected before time t and are still alive at time t :

Figure 2

$$NCprev(t) = \sum_{s=0}^{t-1} NCInc(s)F(t-s-0.5) \tag{2}$$

where $Ncprev(t)$ is the prevalence of infected people at time t expressed as an absolute number, $NCInc(s)$ is the number of new infections occurring between time s and $(s+1)$, and $f(t)$ is the probability that an individual will survive at least t years after being infected.

As noted in Salomom & Murray (2001), half a year is subtracted from the progression to AIDS' function, under the assumption that the average moment of infection within a given time period is the midpoint of that period, e. g. prevalence at year 10 in the epidemic would include those individuals infected during the ninth year who have endured an average of 0.5 year's mortality risk, plus those individuals infected during the eighth year who have endured an average of 1.5 years of mortality risk, and so on.

Expressing equation (2) in proportion rather than in absolute value we have:

Figure 3

$$NCprev(t) / Pop(t) = \sum_{s=0}^{t-1} NCInc(s) / Pop(s)F(t-s-0.5) \tag{3}$$

where $Pop(t)$ is the size of the population at time t , $Pop(s)$ is the size of the population at time s , assuming that the population size is constant over time. Equation (2) may be further simplified as follows:

Figure 4

$$NCPrev_R(t) = \sum_{s=0}^{t-1} NCInc_R(s)F(t-s-0.5) \tag{4}$$

where $NCPrev_R(t)$ is the proportion of the population who have prevalent infection at time t and $NCInc_R(s)$ is the incidence of new infection between time s and $(s+1)$,

expressed as a proportion of the population at time s . If the population size changes over time, then

Figure 5

$$NCPrev_R(t) = \sum_{s=0}^{t-1} NCInc_R(s) \frac{Pop(s)}{Pop(t)} F(t-s-0.5) \tag{5}$$

We considered a point process of new HIV infections and assume that the distribution of the incubation periods (from infection to AIDS diagnosis) is independently and identically distributed random variables with probability density function PDF (t). Let t be the period between infection and AIDS diagnosis and $f(t)$ be the PDF of this incubation period t . We always describe the PDF of the incubation period of HIV infection with the use of weibull distribution (Anderson et al, 1991; Nishiura et al, 2004; Brookmeyer & Gail, 1994 and Wai-Yaum, 2000). This could be expressed as follows;

Figure 6

$$f(t, \alpha, \beta) = \alpha t^{\alpha-1} \beta^{-\alpha} \exp[-(t/\beta)^\alpha] \tag{6}$$

where α and β are the shape and scale parameters respectively.

The logistic model has an age long application in epidemic modeling of infections disease with particular reference to HIV/AIDS. For details see Haberman (1990), Fuhrer, (1998), Hendriks et al (1992, Taylor (1989), Brookmeyer and Damiano (1989), Arzrouni (2004), Rosenberg, Gail and Pee (1991), Daley and Gani (2005). The generalized logistics model is given by:

Figure 7

$$f(t, \mu, s) = \frac{\exp(t-\mu) / s}{s [1 + \exp[-(t-\mu) / s]]^2}, s > 0 \tag{7}$$

where μ is the location parameter and $s > 0$ is the scale parameter. Based on the above backgrounds we propose a four-parameter logistic model, equation (8), for the incidence of HIV/AIDS in the North Central Zone of Nigeria.

Figure 8

$$NCInc_R(s) = (\alpha_{NC} - 1) s^{1/2} + 4\beta_{NC} \exp \left[- \left(\frac{s - \mu_{NC}}{\lambda_{NC}} \right) \right] \left[1 + \exp \left[- \left(\frac{s - \mu_{NC}}{\lambda_{NC}} \right) \right] \right]^{-2} \tag{8}$$

where $NCInc_R(s)$ is the incidence of new infection between time s and $(s+1)$ and λ_{NC} is the rate /level of intervention activities (a small value of λ_{NC} caused the incidence to increase rapidly and vice versa). μ_{NC} is the initial proportion

of adults population that is at risk of infection (it determines the peak of the epidemic (UNAIDS, 2003)), μ_{NC} is the incidence rate/pattern adjustment parameter (it determines the pattern of infection overtime, higher value of which implies faster pattern of infection and vice versa and $\pi_{NC} > 0$ is a parameter incorporated to cater for the behaviour of the entire curve in response to the intervention program (large value of π_{NC} stretches out the curve and hence implies low incidence, which further implies high level of intervention activities and vice versa).

Our model overestimated the incidence rate, particularly, prior to the peak incidence a further modification of equation (8) was necessary, which yields the parametric model for the incidence curve of the HIV/AIDS in the North Central Zone given by the four-parameter model:

Figure 9

$$NCInc_{\lambda}(s) = \begin{cases} \alpha_{NC}s + 4\beta_{NC} \exp\left[-\left(\frac{s-\mu_{NC}}{\lambda_{NC}}\right)\right] \left[1 + \exp\left[-\left(\frac{s-\mu_{NC}}{\lambda_{NC}}\right)\right]\right]^{-2}, & s \leq \mu + \alpha \\ (\alpha_{NC}-1)s^{1/2} + 4\beta_{NC} \exp\left[-\left(\frac{s-\mu_{NC}}{\lambda_{NC}}\right)\right] \left[1 + \exp\left[-\left(\frac{s-\mu_{NC}}{\lambda_{NC}}\right)\right]\right]^{-2}, & s > \mu + \alpha \end{cases} \quad (9)$$

where all the parameters are as defined earlier, in equation (8) above.

Stage Modeling (combining models prior to and after a specified time point e.g. treatment initiation, awareness campaign etc. is a usual practice in HIV/AIDS modeling see Solomon & Wilson (1990), Salomon & Murray (2001) and Brookmeyer and Liao(1990) for details.

DISCUSSION OF RESULTS

We present the model for the prevalence of HIV/AIDS (%) as well as the number of Adults living with HIV among sites inside major town (IMT), outside major town (OMT) and the North Central Zone (NCZ) in fig 1 and 2 respectively. And the models for the incidence are presented in fig 3 and 4. In 2002, the zonal prevalence at ANC sites was 4.65% (IMT: 3.56% and OMT 5.49%) with a range of 0-6.22% and 0-7.40% for the IMT and OMT sites respectively.

Figure 10

Figure 1: UNAIDS Models for HIV prevalence (%) (NCZ Nigeria)

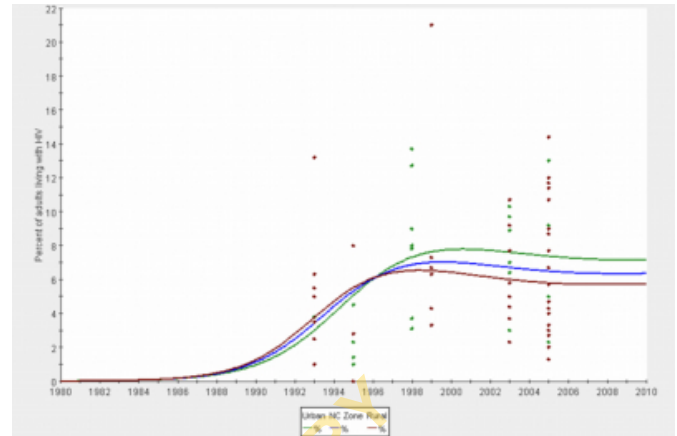
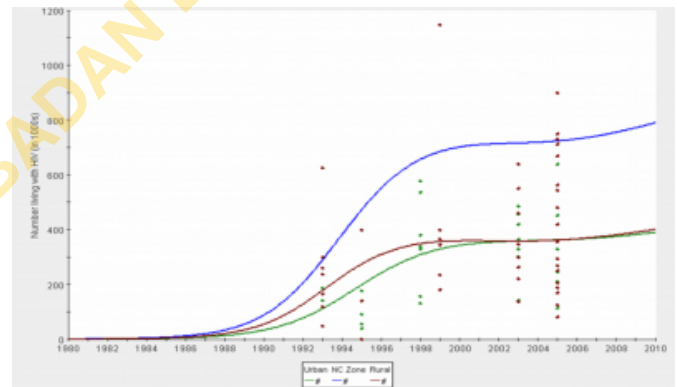


Figure 11

Figure 2: UNAIDS Models for Number living with HIV (NCZ Nigeria)



Similarly, the incidence rate for the zone for the year 1997 where the peak occurred was 0.91% (IMT: 0.68% and OMT 1.07%) when compared to the 2005 incidence rate; 0.53% (IMT: 0.39% and OMT 0.66%), there is an average decline in the result. This agrees with the local results in the prevalence rate (FMOH, 2005). However, we project a little higher estimate: 0.58% (IMT: 0.42% and OMT: 0.71%) for the end of 2007 and 0.63% (IMT: 0.47% and OMT 0.77%) for year 2010.

Figure 3 shows the fit of equation (8) to the incidence rate (%), which shows an evidence of over estimation at the early stage of the epidemic. However, figure 4 presents the fit of equation (9) to the data.

From the SPETRUM-AIM module, a total of 378,000 people are expected to die as a result of AIDS in 2010, a bulk of which arises from the situation among sites outside major town. This is reasonable as the available vaccine

centres (if available) are sited in the Major towns.

CONCLUSION

We present results of the proposed logistic model to the HIV/AIDS surveillance data from the North Central Zone of Nigeria. A comparison of both the prevalence and incidence rate between the IMT and OMT suggest that the North Central Zone of Nigeria is experiencing a rural epidemic. Although studies from some Sub-Saharan African Countries showed a relatively higher estimates for the non-urban sites (see Salomon and Murray (2001), Hladik et al (2006), the North Central Nigeria is dominated by rural surveillance sites.

Figure 12

Figure 3: The Logistic Model fitted to the Incidence (%)

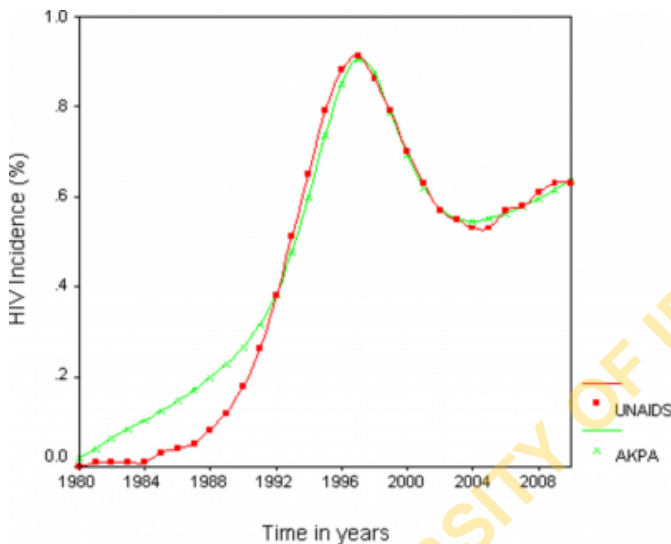
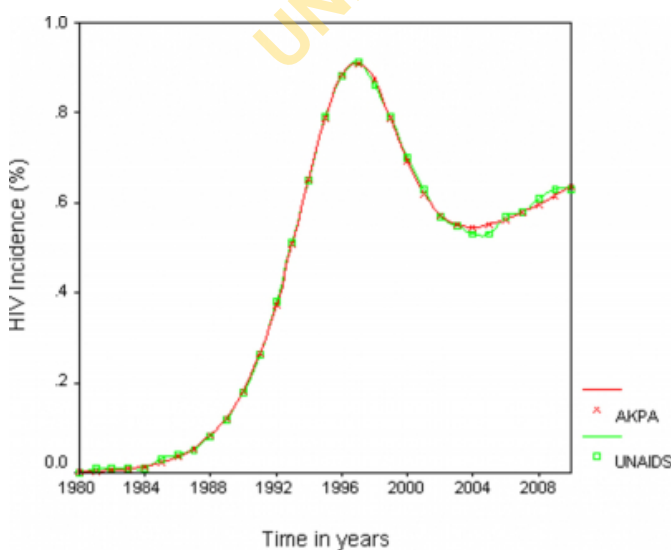


Figure 13

Figure 4: The Stage Model fitted to the Incidence (%)



The four parameters in our model contributed significantly to the growth and decline in the epidemic. The estimates of the parameters with their standard errors and confidence limits are presented in table 1. One of the key assumptions of our model was that, Sentinel data from pregnant women attending antenatal clinics is representative of the general situation of the epidemic in the entire population in the zone. There have been a handful of studies that have addressed the question of whether prevalence rates in antenatal clinics sites were representative of the population prevalence rate (Salomon & Murray, 2001.) One of the most critical question in the focused zone and in Nigeria generally would be whether the Sentinel sites are representative of the zone been modeled. These and some other issues are left out for future direction.

One of the most important parameter in our model is - the rate of intervention activities λ_{NC} . A slight change in the parameter will drastically reduce or increase the incidence rate depending on whether the change is an increase or a decrease respectively.

Figure 14

Table 1: Estimate of the Modeled parameters and confidence Intervals.

Param	Value	Std Error	t-value	95% Confidence Limits	P> t
α_{NC}	1.040896537	0.000407977	2551.358012	1.039987507 1.041805568	0.00000
β_{NC}	0.536512559	0.014891865	36.02722324	0.503331415 0.569693703	0.00000
μ_{NC}	17.86969630	0.221521554	80.66798016	17.37611552 18.36327708	0.00000
λ_{NC}	1.753316872	0.106145024	16.51812597	1.516811020 1.989822723	0.00000

The inhabitant of this zone are predominantly uneducated farmers who regards ideas of the educated as important. Hence, enlightenment campaigns, provision of drugs and some other intervention strategies go a long way to influence their risk behaviours.

The limitation of our model includes among others: the fact that our model is only for the adult population. Also, it can be used to make short term projection only, if a longer term projection is desired, we suggest that transmission dynamics modeling approach should be used.

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