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Demographic Impact of AIDS in a Low-fertility Urban African Setting: Projection for Addis Ababa, Ethiopia

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ABSTRACT

The study estimated the potential demographic impact of acquired immunodeficiency syndrome (AIDS) in a low-fertility urban setting in sub-Saharan Africa. The prevalence of human immunodeficiency virus (HIV) projected using a deterministic mathematical model was put into the AIDS Impact Model (AIM) of the SPECTRUM Policy Modelling System to estimate the potential demographic impact of AIDS in Addis Ababa, Ethiopia. Demographic indicators from 1984 (the start of the HIV epidemic in Ethiopia) to 2024, including and excluding the HIV epidemic, were compared. Addis Ababa is experiencing a demographic transition in which the total fertility rate has declined from 3.8 to below replacement level over the last 20 years. The prevalence of HIV is predicted to stabilize at 10% in adults, resulting in a total number of people living with HIV at 200,000 and a cumulative number of deaths due to AIDS at 50,000. About 60% of adult deaths can be attributable to AIDS by 2000. The epidemic is predicted to reduce life expectancy by 10 and 17 years in 2000 and 2024 respectively, and to turn to negative, the rate of natural increase after 2009. Accordingly, the rate of natural increase will be -0.18%, -0.35%, and -0.71% per annum by 2009, 2014, and 2024 respectively. Population growth is expected to continue with or without HIV, as a result of high net in-migration, although data for migration are scanty. In a low-fertility urban society of Africa, this study shows the potential for the HIV/AIDS epidemic to turn the rate of natural increase to negative.

Key words: HIV; Acquired immunodeficiency syndrome; Mortality; Population growth; Fertility;
Life expectancy; Ethiopia

INTRODUCTION

Ethiopia has been experiencing a severe epidemic of human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS) during the past 15 years, as in most of Africa. The first AIDS cases were diagnosed in hospitals of Addis Ababa, the capital city, in 1986 (1). High rates of HIV prevalence were soon detected along the main trading roads of the country, with HIV seroprevalence rates of 17% among 6,234 commercial sex workers and 13% among 468 truck drivers working along these roads in 1988 (2,3). In 1994, data from 11 urban blood bank centres showed that the prevalence of HIV varied from 5% to 20%, confirming the severity of the epidemic in urban areas (4). By 2000, the Joint United Nations Programme on HIV/AIDS (UNAIDS) estimated that three million people were living with HIV/AIDS in Ethiopia, making it the country

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with the third largest HIV-infected population in the world (5). However, the scale of the epidemic remains uncertain, especially in the rural parts of the country where more than 80% of the people reside. In contrast, the epidemic is relatively well-documented in the capital city of Addis Ababa. A community-based survey, carried out in 1994, estimated the prevalence of HIV at 7% among adults aged 15-49 years, with a peak of 16.3% for men and 11.8% for women aged 25-29 years (6). Such an epidemic is expected to have an impact on the demographic structure of the city, and this is the focus of the present paper.

The prediction of the impact of AIDS epidemic on the demographic structure of a population must take into account the demographic changes occurring independently of the epidemic. In the past two decades in Addis Ababa, fertility has dropped considerably from a high of 3.8 children per woman (total fertility rate, TFR) in 1978 to a low of 1.8 in 1994 (7-10). This was corroborated by a Demographic and Health Survey conducted in 2000, which recorded a TFR of 1.9 in Addis Ababa (11). Although mortality has shown a declining trend over the past two decades, it remains among the highest in sub-Saharan Africa (7). Addis Ababa is also characterized by a high level of migration from different parts of the country (12), although recent data are scanty. Most previous studies on the demographic impact of the AIDS epidemic have been carried out in high fertility societies, predominantly at the national level (13-15). The present study is different in estimating the potential demographic impact of AIDS in a low-fertility urban community of sub-Saharan Africa.

MATERIALS AND METHODS

Description of the setting

Ethiopia covers an area of about 1.1 million sq km between latitude 3° and 18° North. With 61.1 million inhabitants in 1994, the country has the third largest population in Africa. More than 80% of the people live in rural areas (7). The country is among the least developed in the world in terms of economic status and living standard of its people. Ethiopia has experienced extensive social and political upheaval, recurrent drought and famine, war and extensive environmental degradation, which have negative impact on the overall national development activities of the country. As a result, the country is characterized

by high infant and child mortality, low level of life expectancy, massive population movement, and poor infrastructure. Over 2.5 million people live in Addis Ababa, the capital city of Ethiopia. Its altitude ranges between 2,300 and 2,700 metres. The city is organized into five zones, 28 districts, and 305 kebeles (the lowest administrative entity which refers to urban dwellers associations). The population of Addis Ababa is growing at the rate of 2.4% per annum, predominantly due to the high influx of people from different corners of the country. Although the city is expanding rapidly, the existing situations clearly indicate that the carrying capacity of the city in terms of infrastructure and social services has been surpassed. The city ranks among those cities in Africa with the highest infant and child mortality rates and poor socioeconomic infrastructure.

Prediction of HIV epidemic

This study combines model projections of the HIV epidemic with those of the population structure of Addis Ababa. Comparisons were made between simulations including and excluding the HIV epidemic.

The EpiModel used by the United Nations (UN) and the World Health Organization to project the future course of HIV infection has several limitations. First, the EpiModel is an estimation model which is useful in making short-term projection. The projection is based on three key assumptions: year in which HIV infection first became widespread; number of people alive with HIV infection in a recent year; and shape of the infection curve. The usual assumption is a gamma curve (16). In most cases, it is up to the modeller to decide where the epidemic curve in the current year lies on. Moreover, it does not take into account the demographic structure and sexual activity of the population, which are relevant in understanding the course of HIV epidemic in an area. It has, thus, limited utility for the present study.

We, therefore, employed a deterministic mathematical model to project the course of HIV epidemic in Addis Ababa. This model was found to be more appropriate to fulfil the intended objective. The results of the model are presented elsewhere (17). Only brief details are given here. The structure of the model is based on that published by Garnet and Anderson (18), modified to account for changing demographic schedules, i.e. the assumption of a stable age distribution is relaxed, and migration effect is included, which are relevant for capturing a better picture of the epidemic in Addis Ababa. The model

compartmentalizes the population into three groups, namely susceptible (HIV-negative population), HIV-infected (divided into 3 stages of infectivity), and AIDS cases. The model predicts changes over time in numbers of individuals within each compartment with respect to age, gender, and sexual-activity class (divided into low and high). Those with 0-2 new partner(s) per year made up the low-activity class, and those having over two new partners per year were classified as the high-activity class. The force of infection, through sexual transmission in susceptible individuals of specified age, gender, and activity-class, is defined as the summation of effective contacts (i.e. sexual contacts that result in the transmission of the virus) with HIV-infected individuals of the opposite sex, across age and activity-class, and stages of HIV infection. The force of infection is determined by the probability of transmission of HIV from an infected person per partnership, given the proportion of infected persons in the population and the average number of new sexual partners per year. Transmission is assumed to be via heterosexual contact, or perinatally, and excludes individuals with AIDS. As the epidemic proceeds, the rates of change of sexual partners are continually updated to keep a balance of

the population of Addis Ababa or elsewhere in Ethiopia, and biological parameters appropriate to transmission of HIV and progression of disease appropriate to the African context from published literature. Model sensitivity was explored in relation to parameters for which there was a considerable uncertainty, with the largest effects arising from the differences in mixing patterns between the different activity-groups and the method of compensation of partnerships as the disease progressed.

Projections from the assumed start of the epidemic in 1984 were compared with the 1994 survey data as a method of model validation. In this study, a single HIV prevalence trajectory from 1984 to 2024 was used, which provided the best fit to the age-structured seroprevalence data from the representative citywide HIV survey conducted in 1994 (6). As shown in Figure 1, the prediction is that the prevalence of HIV rose rapidly from the late 1980s to a peak of 11% in 2000, declining thereafter only slightly with prevalence of around 10% by 2024. The predicted levelling off of the epidemic is a result of saturation of the most susceptible group in the population. This is explained by the fact that entry of

Fig. 1.   Predicted HIV prevalence, Addis Ababa, 1984-2024
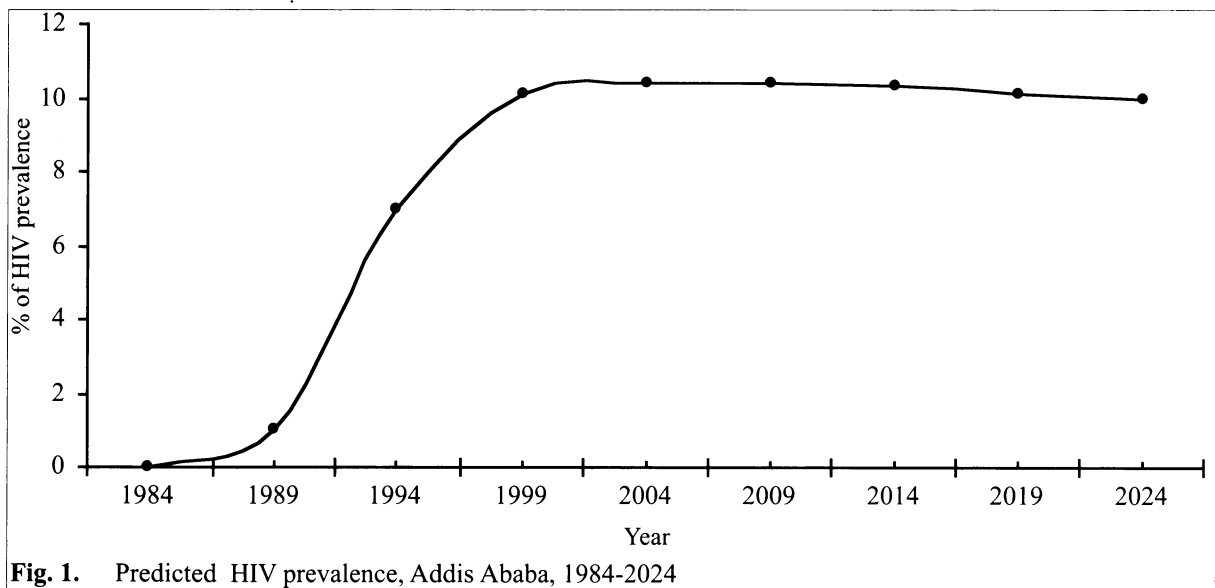
supply and demand. Age-specific fertility and mortality rates are time-dependent; AIDS cases are assumed not to have children and are subject to an increased age-specific case-fatality rate. The model was parameterized using available demographic and behavioural data from

new uninfected group members and exit of infected members due to death and migration could cause equilibrium to be reached. This, however, does not mean that the incidence of HIV is zero; this simply implies that new cases are balanced by death and migration (19).

Data on the predicted prevalence of HIV were put into the AIDS Impact Model (AIM) to predict the future HIV-infected population, number of AIDS cases, and number of deaths due to AIDS by age and gender for the prediction period. For that purpose, the AIM uses various sets of assumptions on the mother–to-infant HIV transmission rate, and it also estimates the number of children developing AIDS and dying of HIV infection based on assumption for the incubation period among infants. Assumptions used in modelling the HIV epidemic in this projection are detailed in Table 1. The AIM, one of the components of the SPECTRUM Policy

Table 1. Assumptions used on HIV/AIDS parameters, SPECTRUM

HIV/AIDS parameter	Parameter value
Death rate of infants with AIDS in the first year	67%
Life expectancy after onset of AIDS	1 year
Reduction in fertility among HIV-positive women	30%
Perinatal transmission rate	35%

Cumulative percentage of individuals developing AIDS by number of years since infection (medium variant)

Years since infection	Adults	Children
1	0,0	29,0
2	3,0	62,0
3	5,0	75,0
4	11,0	85,0
5	18,0	90,0
6	28,0	95,0
7	37,0	95,0
8	47,0	95,0
9	58,0	95,0
10	66,0	95,0
11	73,0	95,0
12	79,0	95,0
13	83,0	95,0
14	87,0	95,0
15	90,0	95,0
16	92,0	95,0
17	94,0	95,0
18	95,0	95,0
19	96,0	95,0
20	97,0	95,0

Modelling System, is a computer programme for projecting the impact of the AIDS epidemic. It can be used in projecting the future number of HIV infections, AIDS cases, and deaths due to AIDS, given an assumption about the prevalence of HIV in adults. Further, it can also project the demographic and social development impacts of AIDS. A detailed description on SPECTRUM and its components can be found in a manual (20). In the present study, the outputs from the AIM include the number of HIV-infected people, AIDS cases, and AIDS-related deaths.

Demographic parameters and projection

The starting year for the projection period was 1984 for both demographic and HIV epidemic components. Population distribution by age and gender was obtained from the 1984 census report of Addis Ababa (12). The demographic projection was prepared using DemProj in the SPECTRUM system along with the AIM (21). It follows a standard cohort-component technique of population projection. This method requires assumptions about the future course of TFR, life expectancy, and annual rate of net migration.

Information available on TFR for a number of years on Addis Ababa is used for supporting assumptions about future trends. The TFR rarely declines at a constant pace throughout an entire demographic transition. Rates of decline are often slow at first, increase during the middle of the transition, and slow down again as the rates approach replacement-level fertility (21). The changes in TFR over time were extrapolated from the observed levels in the 1984 Census (12), the 1990 Family and Fertility Survey (22), the 1994 Census (7), the 1995 Fertility Survey of Addis Ababa (8), and the 2000 Demographic and Health Survey data (11). Three different variants of fertility change (low, medium, and high) were used in the projection process. The medium variant used after 2000 was based on the fertility level found at the 2000 Demographic and Health Survey (11), i.e. 1.9 children per woman. As a high variant assumption, a replacement-level fertility (2.1 children per woman) was set, and for the low variant, a rate of 1.7 children per woman was assumed. Assumptions on fertility are detailed in Table 2. However, most discussions made on the paper are based on the medium-term assumption. The age pattern of fertility is assumed to follow the UN sub-Saharan Africa pattern (21), which is in-built in the SPECTRUM system.

Assumptions about life expectancy followed the UN model schedule. This schedule assumes that life expectancy at birth, for males and females, increases by 2.0 to 2.5 years over each five-year period when life expectancy is less than 60 years and then increases at a slower rate at higher levels (21). The Coale-Demeny

North model life-table, which is assumed to be an appropriate choice for Addis Ababa (7,12), was applied to fit the age pattern of mortality for the data.

prevalence of HIV in adults would plateau at 11% between 1999 and 2004, before declining and stabilizing at 10% for the remaining projection years (Fig. 1).

Table 2. Assumptions used on the total fertility rate in Addis Ababa during 1984-2024

Total fertility rate	Year of projection							
	1984-1989	1989-1994	1994-1999	1999-2004	2004-2009	2009-2014	2014-2019	2019-2024
Low variant	3.2	2.7	1.9	1.7	1.7	1.7	1.7	1.7
Medium variant	3.2	2.7	1.9	1.9	1.9	1.9	1.9	1.9
High variant	3.2	2.7	1.9	2.1	2.1	2.1	2.1	2.1

Considerable uncertainty exists in the projection of net migration and the age distribution of migrants for the population of Addis Ababa. Most recent data are derived from the 1984 census, in which a net migration of 17/1,000 for both the sexes was described, and the Central Statistical Authority of Ethiopia assumes this rate to be almost constant in most population projection exercises for Addis Ababa (7,12). In the present study, the same assumption was followed.

On top of the outputs from the AIM, the population growth rate, rate of natural increase, life expectancy, etc. are estimated. These demographic parameters were estimated in a projection with and without AIDS and were then compared.

It is estimated that, in 2000, about 200,000 people were living with HIV in Addis Ababa. By 2024, the number of people with HIV may reach a quarter of a million. The model predicts that a cumulative total of 50,000 people had died of AIDS by 2000. By 2024, the cumulative number of AIDS-related deaths is predicted to exceed half a million (data not shown).

Population growth and population size

The rate of natural increase will turn to negative after 2009 as a result of the HIV epidemic (Fig. 2). Indeed, under the medium variant fertility assumption and in the absence of the HIV epidemic, the annual rate of natural increase would have been 0.57% and 0.14% in 2009 and
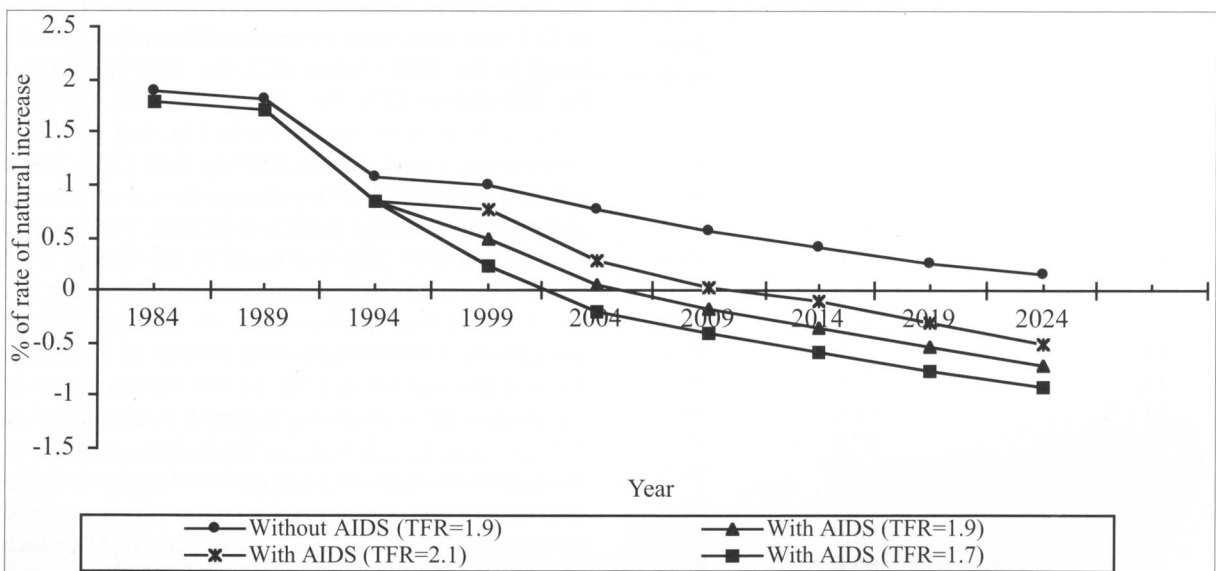

Fig 2.   Predicted rate of natural increase with and without AIDS, Addis Ababa, 1984-2024

RESULTS

Prediction of number of AIDS cases and deaths

The prediction of the HIV/AIDS epidemic using the deterministic mathematical model showed that the

2024 respectively. However, in the presence of the HIV epidemic, the annual rate of natural increase for the same years is predicted at -0.18% and -0.71% respectively. The annual population growth rate will not turn to negative, however, due to the net effect of migration

(Fig. 3). In the absence of the HIV epidemic, the annual rate would have been 2.64% in 1999, 2.0% in 2009, 1.3% in 2019, and 1.1% in 2024. With the HIV epidemic, the corresponding figure is 2.1% in 1999, 1.29% in 2009, 0.55% in 2019, and 0.36% in 2024.

1989 onward. By 2000, about 60% of deaths among adults were attributable to AIDS, and by 2024, over 70% of deaths among adults will be attributable to AIDS. As a result, and also in relation to childhood mortality, life expectancy will have dropped by nine years in 2000,
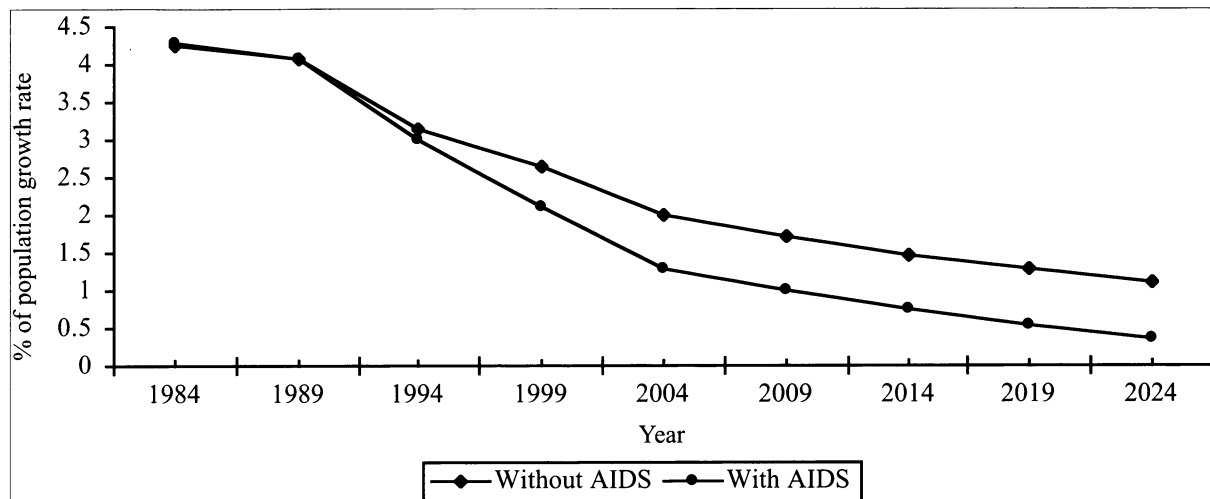
Fig. 3. Predicted population growth rate with and without AIDS, Addis Ababa, 1984-2024
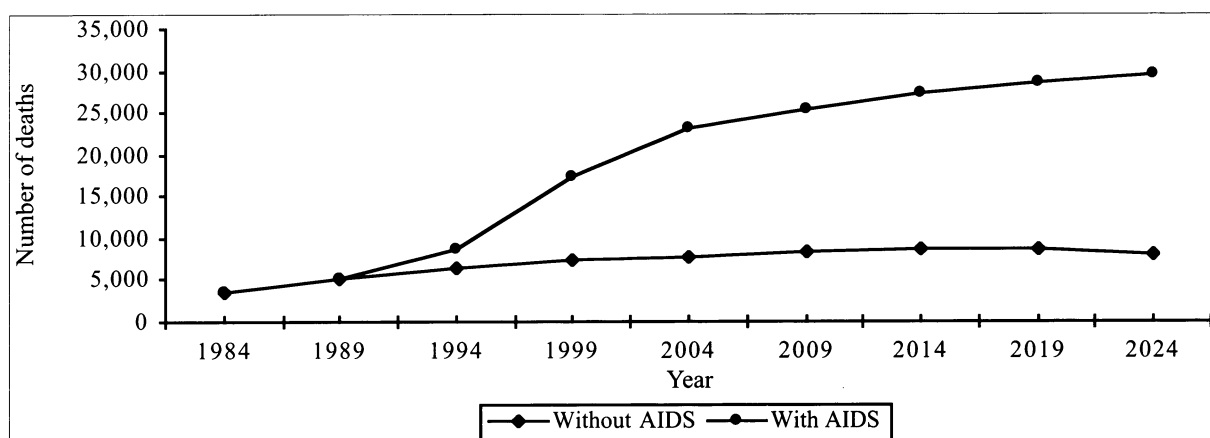
Fig. 4. Predicted adult deaths with and without AIDS, Addis Ababa, 1984-2024

As a result of the decrease in the annual growth rate, the total population size of Addis Ababa will be lower in the presence of the HIV epidemic. The effect became noticeable after 1994, and the deficit in population size reaches 50,000 (2.38 vs 2.43 million) by 2000, and will reach 660,000 (3.01 vs 3.67 million) by 2024.

Adult mortality and life expectancy

The AIDS epidemic is known to have a substantial impact on adult mortality and also life expectancy. As shown in Figure 4, adult mortality was affected from

14 years in 2004, and 17 years in 2024 compared to what it would have been in the absence of the HIV epidemic (Fig. 5). It is currently predicted to stabilize at 47 years, while it was expected to reach 64 years by 2024.

DISCUSSION

This study addressed the demographic impact of AIDS in Addis Ababa. Addis Ababa is unique as it combines a severe epidemic of HIV with one of the lowest TFR of urban Africa. In such context, the rate of natural increase of population is expected to become negative as early as

in 2009. This would be the first documented negative rate of natural increase in conjunction with a severe epidemic of HIV in the world.

where an HIV prevalence survey was carried out by selecting a random sample of the entire population of the city (6). These data were at the backbone of the
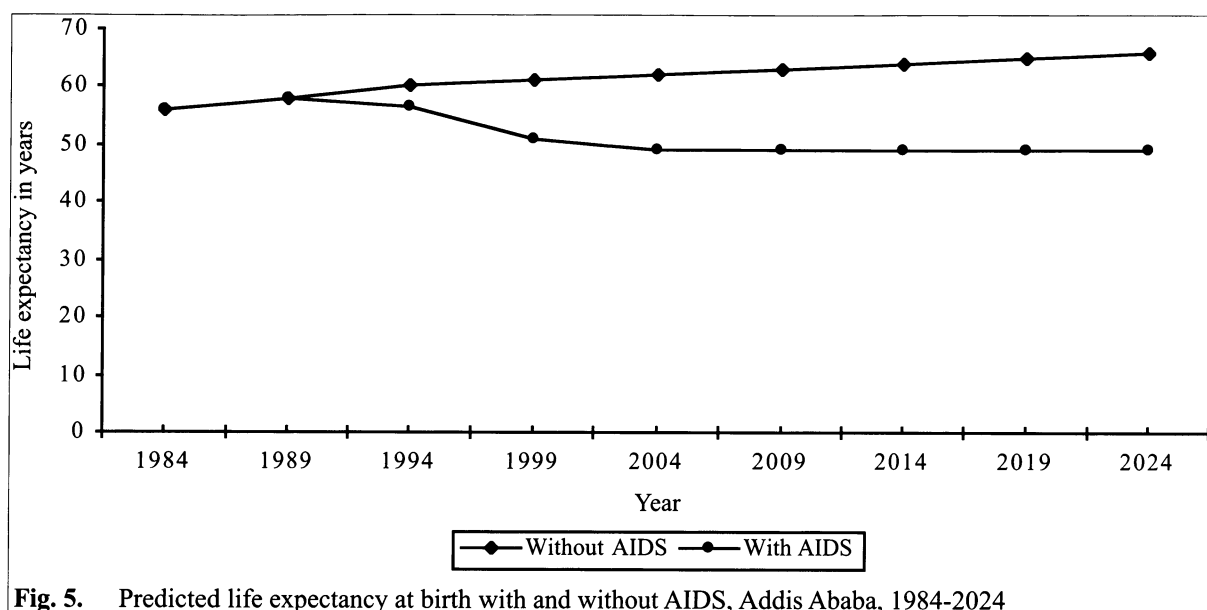

Fig. 5.   Predicted life expectancy at birth with and without AIDS, Addis Ababa, 1984-2024

One may first question the validity of the TFR estimated during the various surveys used for references in this study. Although reporting on births may indeed be subject to biases, the consistently low TFR calculated over several surveys (1984 and 1994 Census, 1990 and 1995 Family and Fertility Survey, 2000 Demographic and Health Survey) carried out by different institutions adds weight to the finding (7-11). Also, the narrowing of the Addis Ababa population age-pyramid among those aged less than 10 years suggests a major reduction in fertility rate in the past 10 years (7). Finally, several important societal changes took place in Addis Ababa in the past three decades and may contribute to the decrease in fertility. Specifically, some most important determinants of fertility have changed over the past 20 years (8,9,22). These are: increase in age at marriage (mean age at marriage increased from 20 years in 1974 to 27 years in 1995), rise in the proportion of unmarried women at the age of 30 years (from 7% in 1974 to 42% in 1995), and high rate of contraceptive prevalence among sexually-active women in the city (42%). Although previous data on contraceptive use are scanty, the use is expected to be much lower than the current rate.

The estimates used for the prevalence of HIV and its projections are based on solid data and are quite conservative. Addis Ababa is one of the few African cities

projections made in this paper. Data available from other surveys, including sentinel surveillance among pregnant women, and data from visa applicants and blood donors indicate a stabilization of HIV prevalence rates in Addis Ababa in the second half of the 1990s in accordance with the model used in this study (4).

Previous attempts to model the spread of HIV and its impact on population growth have produced quite diverse results. Some researchers have reported that AIDS-related mortality will lead to negative population growth (14,24,25). Others reported that AIDS-related mortality will cause a significant increase in overall mortality but that this increase will not be so large as to lead to negative population growth (25-27). All researchers, however, agreed that, in an African setting, negative population growth will not occur unless the prevalence of HIV among adults reaches 30-50% (19). Way and others argued, there is evidence from both simulation modelling and epidemiological data that the epidemic of HIV does plateau (26). In some cities (Lilongwe, Malawi; Lusaka, Zambia), these levels of plateauing might well approach 30-40%. The rural areas are likely to plateau at a much lower level. Therefore, it is very unlikely that levels of 30-50% will be reached for any area as large as a country (19). According to reports by the U.S. Census Bureau, population growth

rates will remain positive in all sub-Saharan African countries but will be reduced significantly due to AIDS. For all 21 sub-Saharan African countries, the annual rate of population growth from 1990 to 1995 will be 2.2% rather than the 2.6% that would be projected without AIDS (24). These studies, however, were conducted at the national level where fertility, in general, estimated well above replacement level, and the prevalence of HIV is not as high as those observed in specific cities.

In these modelling exercises, much emphasis has been put on the impact of AIDS on the mortality rate and its subsequent impact on the population growth, while potential variations in the fertility rates and their impact on the population growth were not fully explored. This study stresses that the high prevalence levels described above for the population growth to turn negative may not need to be reached, once one takes into account the heterogeneity of the fertility rates which exist across the African continent. Although this argument is theoretically sound, there is, however, no African country with nationwide fertility rate close to the replacement level. However, as in Addis Ababa, one cannot rule out the possibility of observing low fertility rates in some specific communities in Africa. The last important component of the population growth rate is migration. It is, perhaps, the most difficult one to apprehend as quality data on its magnitude are rare and as predictions are almost impossible to make. Migration was usually ignored in previous modelling work aiming at national predictions on the assumption that most migrations occur within countries and that the balance across countries might be zero. The situation is clearly different for most African cities which experience high positive net migration rates. As was shown for Addis Ababa, these migration rates are likely to overwhelm the rate of natural increase, so that the rate of population growth will remain positive in most urban areas of Africa.

Other findings of this study describe the marked impact of HIV epidemic on young adults, as was shown in earlier reports (28). The impact of epidemic is much more severe among adults aged 15-49 years than among any other section of the population. It is estimated that AIDS-related mortality represents 60% of all adult deaths by 2000, which suggests that AIDS is becoming the leading cause of adult mortality in Addis Ababa. Adults represent the most economically-active section of the population, and the loss of this section of the population will have a negative impact on the national economic development activities of the country. Moreover, family disintegration and the resulting AIDS orphans are among the many social problems the AIDS epidemic poses on the society. The study also revealed that life expectancy at birth will be severely affected by the epidemic of AIDS. The estimated drop was nine years by 2000, and will be 17 years by 2024, with a life expectancy levelling off at 47 years. There are two major reasons for a large effect of the HIV epidemic on life expectancy. First, AIDS causes many deaths of children at very young ages, resulting in the loss of many potential life years. Second, there is a large increase in death among those aged 15-49 years. This group typically has very low death rates. Therefore, young adults with HIV infection are not likely to die of some other causes before dying of AIDS. Similar estimates were produced for six selected countries of southern Africa, where life expectancy had dropped 10-17 years below what it would have been in case the trend of improving life expectancy continued after 1985 (24).

In conclusion, the present study provides an insight into the demographic impact of AIDS in a low-fertility urban setting of Africa. Most importantly, the study revealed that, in a low-fertility society like Addis Ababa, AIDS has the potential to cause negative rate of natural increase even with the prevalence of HIV well below 30%. In addition, the study revealed that the epidemic has already had a significant demographic impact on the population of Addis Ababa and will have even greater impact in the future. However, the future course of the epidemic and its demographic consequences could be altered through effective interventions, such as behavioural change toward safe sex, control of sexually transmitted diseases, and interventions for reducing mother-to-child transmission.

ACKNOWLEDGEMENTS

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