THE SOUTH AFRICAN HIV EPIDEMIC, REFLECTED BY NINE PROVINCIAL EPIDEMICS, 1990 - 1996

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Objectives. To determine by serological examination the annual point prevalence rates of infection with the human immunodeficiency virus (HIV) in representative samples of subjects in the nine provinces of South Africa, 1990 - 1996.

Design. Annual cross-sectional point prevalence surveys conducted in October/November of each year.

Setting. South Africa, including areas that used to be known as self-governing and independent National States.

Subjects. Pregnant women in the age group 15 - 49 years who attend antenatal clinic services provided by the public health services, and who act as an indicator group of the HIV epidemic among the heterosexually active population.

Outcome measures. HIV positivity as determined serologically; done consistently over several years, this serves to monitor the distribution and trend of the HIV epidemic in each of the nine provinces of South Africa.

Results. Empirical data gained from seven annual, consecutive countrywide surveys demonstrate a wide geographical variation in the point prevalence rates of HIV infection. In October/November 1996 the point prevalence rates (%) were as follows: Western Cape 3.09, Northern Cape 6.57, Northern Province 7.96, Eastern Cape 8.10, Gauteng 15.49, Mpumalanga 15.77, Free State 17.49, KwaZulu-Natal 19.90 and North West 25.13. The weighted national average was 14.17%. There are indications that some of the provinces (KwaZulu-Natal and possibly Mpumalanga) might have passed a point of inflection suggesting deceleration in their specific rates of increase. These results are, however, counterbalanced by the exponential growth still being experienced in provinces with large populations such as Gauteng and the Eastern Cape. It is concluded that the net effect of these divergent trends currently affects the national figure only marginally. A major deflection from the exponential growth patterns seen hitherto can be anticipated only once all or most of the highly populated provinces have traversed their respective points of inflection.

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The exponential model significantly explains the HIV epidemics in the provinces. The combination of these provincial epidemics describes the initial exponential phase of the epidemic.

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Ever since the annual national surveys to determine the point prevalence rates of infection with the human immunodeficiency virus (HIV) were begun in South Africa in 1990, widely different results were obtained in the various geographical areas. Now that the previous four provinces and National States have been consolidated into nine provinces these major differences have not only been maintained but have been confirmed in the course of seven consecutive annual surveys.

As far as executive power is concerned the provinces have been invested with the means to play a pivotal part in rendering health services, or alternatively to support and lead the health districts within their respective jurisdictions. This fact, combined with the realisation that the provinces are at different stages of the HIV epidemic, makes it essential for each of them to become increasingly involved in the surveillance of their own HIV situation.

The national data have been published in two parts to date: the situation at the conclusion of the third national survey[1] in which the data pertaining to 1990, 1991 and 1992 were presented, and an update referable to the period 1993 - 1995.[2] Using the whole dataset, 1990 - 1995, and adding the results of the 1996 survey,[3] the epidemic as reflected by a combination of the provincial epidemics is presented here.

METHODS

The method involved in the acquisition of the data, and the planning and execution of the national surveys, have been described fully in the published surveys.[1,2] Greater detail on the development and description of the national surveys has been published in the in-house surveillance instrument of the Department of Health, namely *Epidemiological Comments*.[3-9]

One consequence of the sociopolitical transformation the country has experienced during the same timespan in which these national surveys took place has been the change in geographical boundaries. From 1990 to 1993 the geographical basis consisted of four provinces and ten National States. For the surveys of 1994 - 1996 all this had changed and the surveys were based on the consolidated new provinces. Retrospectively the geographical sites of all specimens were redefined for the years 1990 - 1993 in terms of the new borders of the nine provinces, leading to a coherent dataset. Weighted provincial HIV prevalence estimates were re-calculated with the estimated births per population group in each province as weighting factor. The total dataset for the 7 years therefore consists of weighted estimates for 1990 - 1994 and unweighted estimates

Table I. Estimated HIV provincial point prevalence rates (%) in women aged 15 - 49 years, based on annual national surveys of women attending antenatal clinics of the public health services, South Africa, 1990 - 1996

	N	HIV (%)	95% confidence interval
South Africa			
1990	14 408	0.73	0.50 - 0.96
1991	17 153	1.74	1.28 - 2.19
1992	19 314	2.15	1.86 - 2.44
1993	16 206	4.01	3.56 - 4.45
1994	18 630	7.57	7.01 - 8.12
1995	13 741	10.44	9.86 - 11.03
1996	15 044	14.17	13.45 - 14.89
Western Cape			
1990	5 521	0.06	0.00 - 0.12
1991	1 409	0.08	0.00 - 0.23
1992	1 463	0.25	0.01 - 0.50
1993	1 102	0.56	0.19 - 0.94
1994	2 062	1.16	0.76 - 1.56
1995	1 205	1.66	0.94 - 2.38
1996	1 778	3.09	2.34 - 3.84
Eastern Cape			
1990	451	0.44	0.00 - 1.05
1991	4 229	0.58	0.35 - 0.81
1992	4 316	0.96	0.67 - 1.25
1993	4 195	1.94	1.51 - 2.36
1994	3 743	4.52	3.85 - 5.19
1995	1 768	6.00	4.89 - 7.10
1996	2 031	8.10	6.92 - 9.28
Northern Cape			
1990	953	0.20	0.00 - 0.47
1991	805	0.12	0.00 - 0.36
1992	730	0.65	0.09 - 1.20
1993	750	1.07	0.39 - 1.75
1994	1 277	1.81	1.09 - 2.53
1995	1 254	5.34	4.10 - 6.59
1996	1 137	6.47	5.05 - 7.89
Free State			
1990	992	0.59	0.10 - 1.07
1991	951	1.50	0.73 - 2.28
1992	1 150	2.86	1.94 - 5.21
1993	1 200	4.12	3.03 - 5.21
1994	1 850	9.19	7.94 - 10.44
1995	1 496	11.03	9.44 - 12.62
1996	1 483	17.49	15.57 - 19.41
KwaZulu-Natal			
1990	2 010	1.61	1.06 - 2.17
1991	2 957	2.86	2.17 - 3.54
1992	2 759	4.50	3.61 - 5.38
1993	1 339	9.53	7.96 - 11.11
1994	1 738	14.35	12.22 - 16.48
1995	1 552	18.23	16.31 - 20.16
1996	1 601	19.90	17.68 - 22.12
Mpumalanga			
1990	426	0.38	0.00 - 0.86
1991	1 920	1.21	0.73 - 1.68
1992	2 457	2.23	1.67 - 2.79
1993	2 090	2.40	1.77 - 3.04
1994	1 480	12.16	10.55 - 13.76
1995	1 644	16.18	14.40 - 17.96
1996	2 363	15.77	14.34 - 17.20

Table I. Continued

Northern Province			
1990	389	0.26	0.00 - 0.77
1991	1 859	0.48	0.17 - 0.79
1992	2 556	1.05	0.66 - 1.44
1993	2 092	1.79	1.23 - 2.36
1994	2 763	3.04	2.40 - 3.67
1995	2 250	4.89	4.00 - 5.78
1996	1 407	7.96	6.24 - 9.68
Gauteng			
1990	3 380	0.66	0.66 - 1.00
1991	2 860	1.12	1.12 - 1.66
1992	2 638	2.53	2.53 - 3.23
1993	3 157	4.13	4.13 - 5.06
1994	3 148	6.44	6.44 - 7.25
1995	1 463	12.03	12.03 - 13.70
1996	2 156	15.49	13.58 - 17.40
North West			
1990	286	1.05	1.05 - 2.49
1991	163	6.54	6.54 - 1.20
1992	205	0.94	0.94 - 2.71
1993	281	2.19	2.19 - 4.43
1994	569	6.71	6.71 - 8.80
1995	1 109	8.30	8.30 - 9.92
1996	1 088	25.13	22.31 - 27.95

N = number of specimens tested and included in the weighted analysis.

for 1995 and 1996. The number of specimens tested and prevalence estimates by province and for each year are shown in Table I. This approach corresponds with the original sampling plan and analysis.

Analysis of the data

The analysis of the data comprises two main parts. In the first place the design, format and other details of the analyses that underlie the annual surveys have been described in detail previously.[1,2] It is the second part that is of greater concern in this presentation. Use is made here of a provisional model for comparative purposes, and the derivation thereof is based on various assumptions.

It is taken as read that the HIV/AIDS epidemic has the propensity to afflict to an equal extent all who engage in practices that allow transmission. Distinguishing features of the underlying populations are specifically the extent of risk avoidance and, to a degree, also the prevailing sexual practices, which might vary in accordance with cultural and personal orientation.

In constructing the model these factors have not been taken into consideration. Rather the general epidemic curve of a chronic disease was assumed to apply, leading to the following assumptions.

Assumption 1. The curve of the HIV epidemic follows that of a chronic propagated source.

Assumption 2. From observation, and as a simplification, such a curve is considered to be made up of three distinguishable parts: a first phase rising exponentially, which is bounded by the origin and the point of inflection; a second phase from the point of inflection to the maximum prevalence rate, giving to the combination of these two phases an S-shaped appearance;[10] and a third phase extending from the maximum through the subsequent decline back to zero prevalence, which may take on various patterns, but should not be of any further concern at this juncture.

Assumption 3. Provinces were not exposed to HIV at the same point in time.

Assumption 4. In any provincial series a specific prevalence estimate is identified as a stable point in the provincial epidemic. In all provinces, with the exception of the Free State, the first estimate is assumed to be the stable result. With regard to the Free State, the 1991 result is assumed to be stable.

The model described here is strictly applicable to the first phase of the epidemic, namely its initial sharp exponential rise.

The assumption of exponential growth was tested for each of the provinces by fitting an exponential model,

$y_i = ae^{bx}$

to the observed provincial estimates using a least-squares algorithm.[10]

The model explained more than 90% of the variance in all provinces except Mpumalanga and North West. The differences in the parameters suggest, however, that provinces are not all at the same point of the exponential curve. Further investigation of residuals reflected by the final loss function, where

Loss function = (observed – predicted)^2,

Table II. Exponential fit of observed provincial HIV prevalence estimates for 1990 - 1996

	Final loss	Variance explained
Northern Province		
$y = 0.2368 \times e^{(0.5030\,x)}$	0.0631	99.87%
Western Cape		
$y = 0.0572 \times e^{(0.5699\,x)}$	0.0521	99.29%
Gauteng		
$y = 0.7270 \times e^{(0.4438\,x)}$	3.9349	97.98%
Free State		
$y = 0.8310 \times e^{(0.4368\,x)}$	4.6621	97.95%
Eastern Cape		
$y = 0.4206 \times e^{(0.4296\,x)}$	1.9127	96.50%
KwaZulu-Natal*		
$y = 1.6064 \times e^{(0.4138\,x)}$	7.3988	96.72%
Northern Cape		
$y = 0.1584 \times e^{(0.5400\,x)}$	2.4452	93.93%
North West		
$y = 0.1001 \times e^{(0.7846\,x)}$	48.5810	88.58%
Mpumalanga		
$y = 1.1664 \times e^{(0.3941\,x)}$	52.1585	83.11

* Excludes the 1996 HIV prevalence estimate.
Exponential model: $y = ae^{bx}$.
Dependent variable: prevalence.
Loss function: (observed - predicted)^2.

indicate that the growth model does not fit the observed rates of either Mpumalanga or North West well (Table II).

To develop a model to describe the exponential phase of the HIV epidemic in a heterosexual population, the results of the provincial epidemics were combined.

In order to determine the relative stage of the epidemic at which each province was at the onset of the annual surveys, an iterative methodology using the exponential model $y_i = ae^{bx}$ was followed.

Based on the amount of variance explained by the growth model, the iterative methodology started off with Northern Province. An exponential curve, $y_1 = ae^{bx}$, was fitted to the observed prevalence rates for the years 1990 - 1996 with the time parameter x in 1990 set as x = 3.75. The observed prevalence rate of 0.06% in 1990 in the Western Cape was substituted in y_1 to determine a corresponding x-co-ordinate, say x_2. Obviously, the subsequent x-co-ordinates of the Western Cape's annual values were all in intervals of 12 months compared with x_2, so that a revised exponential curve, y_2, could now be found using the observed prevalence rates of seven consecutive surveys in Northern Province and the Western Cape, i.e. 14 pairs of co-ordinates. The same process was followed to derive revised curves y_i (i = 3, 4, ..., 7) consecutively adding the observed HIV prevalence estimates of Gauteng, the Free State, the Eastern Cape, KwaZulu-Natal and the Northern Cape.

Using the x values estimated by the above method, the results from all provinces were combined to obtain an exponential model describing the initial phase of an HIV epidemic in a heterosexual population:[10]

$y_i = ae^{bx}$.

The full model incorporating all observed prevalence rates explained 84% of the variance, but residual analysis showed that the model did not fit Mpumalanga and North West data well (Fig. 1). A revised model excluding Mpumalanga and North West and explaining 97.8% of the variance is given by

$y = 0.1129\ e^{0.4450\,x}$,

where x denotes time co-ordinate in the epidemic (Table II).

For each province the observed annual prevalence rates were superimposed on the model.

Results

The consolidated data per year of survey and by province, 1990 to 1996, are given in Table III. It is seen that there is great variation in the 1996 prevalence rates between provinces, the range being 3.09 in the Western Cape and 25.13% in North West. With the exception of Mpumalanga, there has been a sustained rise in the rate of HIV infection. In Mpumalanga and North West (where an exceptional increase in HIV rate was found in 1996), an inconsistent epidemic pattern was found. No explanation could be found for this phenomenon.

The empirical provincial data have been superimposed on the common iterative model in Fig. 2. This demonstrates at

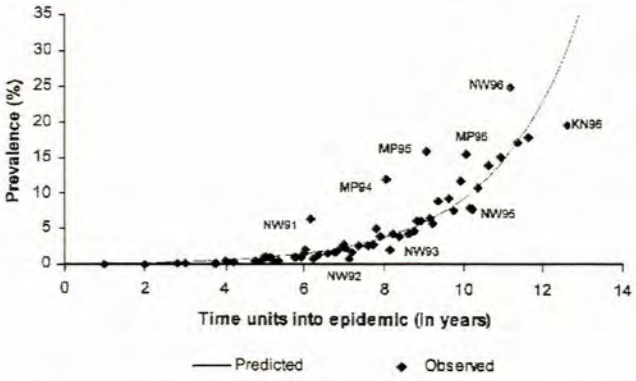

Fig. 1. Provincial HIV prevalence estimates from seven national antenatal surveys, conducted between 1990 and 1996, superimposed on an exponential model model ($y = 0.1129\ e^{0.4450\,x}$).

Table III. Exponential model of the initial phase of an HIV epidemic in a heterosexual population

	Constant a	Time coefficient b
Estimate	0.1129	0.4450
Standard error	0.0194	0.0164
T (46)	5.8060	27.1950
P-value	0.0000	0.0000

Estimated prevalence rate for 1997

	Time parameter (x) (years into the epidemic)	Estimated prevalence rate
Western Cape	8.01	3.94
Northern Cape	9.80	8.84
Northern Province	10.75	13.50
Mpumalanga	11.04	15.39
Eastern Cape	11.21	16.60
Gauteng	11.92	22.68
Free State*	12.35	27.60
North West*	12.15	25.13
KwaZulu-Natal	13.61	48.17

* Under the assumption that the epidemic reaches a point of inflection by the 12th year, these rates overestimate the infection rate.
$y = ae^{bx}$.
Final loss: 37.55.
Variance explained: 96.57%.

what stage of its specific HIV epidemic each province currently find itself — and what to expect in the forthcoming years. A point of inflection where the natural increasing rate of HIV in a heterosexual population starts to slow down is probably reached between the 12th and 13th year of the epidemic. The estimated prevalence rate at the end of 1997 according to the model is given in Table II. In the provinces moving beyond year 12 these are probably overestimates.

Discussion

There are many uncertainties in surveys of this nature. The size, distribution and representativeness of the annual samples

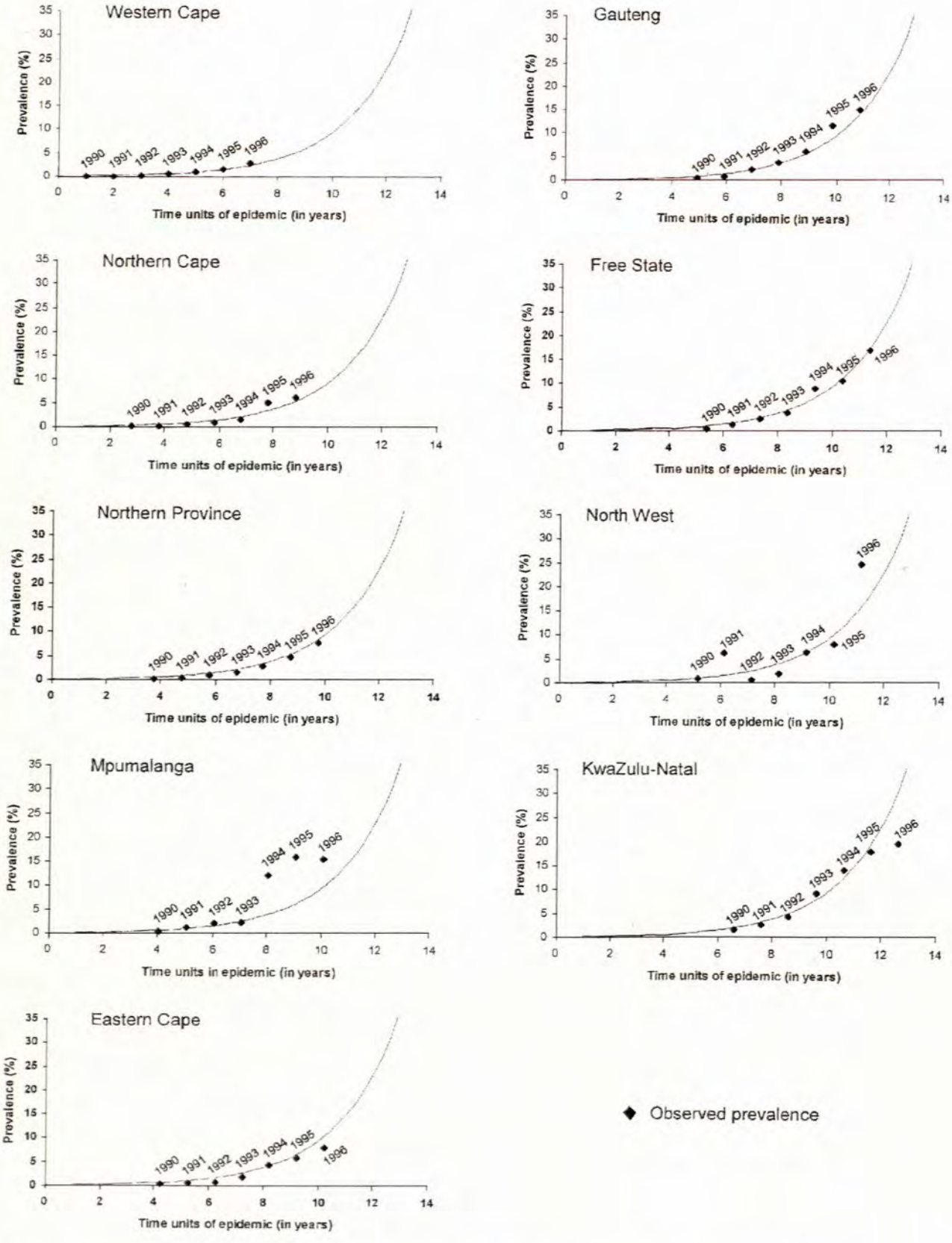

Fig. 2. Provincial HIV epidemics between 1990 and 1996, superimposed on an exponential model (model: $y = 0.1129\ e^{0.4450x}$).

— in fact to begin with the very sampling frame itself — are not perfect. The method of specimen collection, the control thereof, editing the data at source, assembling the data and the analysis thereof are all open to question.

Notwithstanding these many caveats the data are remarkably consistent. These results are and should be seen as an aid to managers at national and provincial level with whom the daunting responsibility to contain and control this epidemic lies. With increased staff and funds it might be possible to improve the quality of the data.

While these may be the only comprehensive and consistently produced data on HIV on a national basis, there remains an onus to continue with those initiatives aimed at more specific, targeted sentinel surveillance programmes. This applies particularly to that important aspect that has not been addressed here, namely to measure the impact of interventions, risk assessments and behaviour modifications and to conduct sociological studies. It is here that the relationship between disease determinants and outcome, and, therefore, also the expected caseload of persons with HIV/AIDS, is most likely to be uncovered.

Regarding the model presented as an interim effort at consolidating the provincial findings, it is evident that it is reaching the end of its useful applicability in several provinces. The results of the 1997 survey and subsequent ones will, it is hoped, allow for a revision of this model to embrace part or all of the next phase of the epidemic.

In the absence of any better comprehensive data on the South African HIV epidemic, both the national and the provincial datasets will have to serve as the compass guiding the team of the AIDS Control Programme.

These data were compiled and analysed by a minuscule staff and at a direct cost that is extremely modest by any standard, namely about R250 000 in 1996. In no small measure this is thanks to the untiring support and unswerving loyalty received from the participating laboratories.

For the indispensable part they played in the sampling procedure and the examination of the specimens the following laboratories, their directors and heads, and their staff at the workbench, are thanked most sincerely: the Virology Laboratories of the Universities of Cape Town, Natal and the Orange Free State and the Department of Obstetrics and Gynaecology of the latter; the National Institute for Virology; the Blood Transfusion Services of the Western Province, the Eastern Province, Border and Natal and the South African Blood Transfusion Service; the South African Institute for Medical Research and its regional laboratories in Northern Province, Kimberley, Bloemfontein, Bethlehem, Kroonstad and Welkom, and the Laboratory of Shongwe Mission Hospital. We wish to thank the then Director-General of the Department of Health, Dr Olive Shisana, not only for permission to publish this report, but also for the empathy and broad understanding she brings to a disease that touches so many aspects of individual and communal life and that has overtaken our country and its health services: AIDS.

References

1. Küstner HGV, Swanevelder JP, Van Middelkoop A. National HIV surveillance in South Africa, 1990 - 1992. *S Afr Med J* 1994; **84:** 195-200.
2. Küstner HGV, Swanevelder JP, Van Middelkoop A. National HIV surveillance in South Africa — 1993 - 1995. *S Afr Med J* 1998; **88:** 1316-1320 (this issue).
3. Department of National Health and Population Development. Seventh national HIV survey in women attending antenatal clinics of the public health services in the Republic of South Africa, October/November 1996. *Epidemiological Comments* 1996/1997; **23**(2): 4-16.
4. Department of National Health and Population Development. First national HIV survey in women attending antenatal clinics, South Africa, October/November 1990. *Epidemiological Comments* 1991; **18**(2): 35-45.
5. Department of National Health and Population Development. Second national HIV survey in women attending antenatal clinics, South Africa, October/November 1991. *Epidemiological Comments* 1992; **19**(5): 80-92.
6. Department of National Health and Population Development. Third national HIV survey in women attending antenatal clinics, South Africa, October/November 1992. *Epidemiological Comments* 1993; **20**(3): 35-47.
7. Department of National Health and Population Development. Fourth national HIV survey in women attending antenatal clinics, South Africa, October/November 1993. *Epidemiological Comments* 1994; **21**(4): 68-78.
8. Department of National Health and Population Development. Fifth national HIV survey in women attending antenatal clinics, South Africa, October/November 1994. *Epidemiological Comments* 1995; **22**(5): 90-100.
9. Department of National Health and Population Development. Sixth national HIV survey in women attending antenatal clinics, South Africa, October/November 1995. *Epidemiological Comments* 1996; **23**(1): 3-17.
10. Farnum NR, Stanton LW. Forecasting series with trends. In: *Quantitative Forecasting Methods*. Boston: PWS Publishing Company, 1989.
11. Nonlinear Estimation. *STATISTICA for Windows*. Tulsa, Oklahoma: Statsoft, 1995.

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