Middle States Geographer, 2014, 47: 102-112

EXPLAINING THE REGIONAL DIFFUSION OF HIV/AIDS IN SOUTHERN AFRICA DURING THE 1990-2000 DECADE

Joseph Semanchik and Ezekiel Kalipeni*
Department of Geography
Colgate University
13 Oak Drive
Hamilton, NY 13346
* Department of Geography
University of Illinois at Urbana-Champaign
Champaign, IL 61821

ABSTRACT: *In this study we use Geographic Information Systems to reconstruct the diffusion of HIV/AIDS in southern Africa between 1990 and 2000, a decade which witnessed some of the highest rates of HIV in the world break out in this region. Utilizing HIV/AIDS rates calculated at antenatal clinics from pregnant women, we use Inverse Distance Weighted (IDW) method to (1) create interpolated smooth surface maps and (2) from the interpolated maps estimate or mine average HIV prevalence rates by country for each year during the decade. The analysis in this paper demonstrates the spatial diffusion of HIV/AIDS from north to south trend in southern Africa over the 1990-2000 decade. The paper further argues that international migration within southern African countries was the vehicle that facilitated the rapid match of the HIV virus into this region from countries further north.*

Keywords: *Geographic information systems (GIS), Inverse Distance Weighted (IDW) method, HIV/AIDS prevalence rates, International migration, southern Africa.*

INTRODUCTION

The Human Immunodeficiency Virus/Acquired Immunodeficiency Syndrome (HIV/AIDS), has instilled fear in countries across the globe. The three most common forms of transmission are having unprotected sex with an infected person, sharing needles with an infected person, and from mother to child through breast feeding or in vitro. Though treatments are now available in the form of antiretroviral therapy, there still is no cure. It is said that the best treatment for HIV is to prevent it. In the 1990-2000 decade, the disease spread like a wildfire in the countries of southern Africa such as Botswana, Lesotho, Zimbabwe and South Africa reaching prevalence rates of over 35% for some countries such as Botswana.

Given the historical background of international labor migration in southern Africa, and the fact that the highest HIV/AIDS rates were being recorded in this region, we decided to use Geographic Information Systems in reconstructing the diffusion of HIV/AIDS for the years 1990-2000, a decade which witnessed some of the highest rates of HIV in the world break out in this region. Utilizing HIV/AIDS rates calculated at antenatal clinics from pregnant women we use inverse distance weighted (IDW) method in a GIS environment to (1) create interpolated smooth surface maps; (2) from the interpolated maps estimate or mine average HIV prevalence rates by country for each year during the decade; and (3) explain the variations by examining rural-urban and international labor migration. We demonstrate the role of migration, whether at the national or international level, by examining the migration flows in Zambia (rural-urban migration) and South Africa (international migration). The central argument the paper advances is that the spatial diffusion of HIV/AIDS from north to south trend in southern Africa over the 1990-2000 decade can be explained by the unique forms of rural to urban and international migration that was instituted during the colonial era. This, we argue, was the main vehicle that facilitated the rapid match of the HIV virus into this region from countries further north.

The role of migration in the spread of HIV/AIDS and for that matter other infectious diseases is nothing new. The migration hypothesis with reference to HIV/AIDS was first advanced by Smallman-Raynor et al. (1992). There have been quite a substantial number of studies examining the role of labor migration in southern Africa mostly at the individual level or household levels (See for example: Campbell, 1997; Anglewicz, 2012; Avogo and Agadjanian, 2013; Brockerhoff and Biddlecom, 1999). However, studies which use GIS to demonstrate the spread of an infectious disease are very rare. Our study joins a limited but growing use of GIS in HIV analyses in Africa. Although occasional studies during early parts of the epidemic demonstrated the value of geographic analysis in understanding HIV prevalence, risk, and spread; including in mapping the distribution of at-risk populations of commercial sex workers and uncircumcised males (Obbo, 1993; Webb, 1994; EPA, 2004; Krivoruchko, 2011), very few studies have analyzed spatiotemporal variation in HIV prevalence (Getis and Ord, 1992), and few still have been able to utilize GIS to make estimates of HIV/AIDS rates from the generated GIS maps (see for example Gould, 1993; Kalipeni and Zulu, 2008; Moise and Kalipeni, 2012). In this regard, the main purpose of this paper is twofold: (1) create a series of interpolated smooth surface maps using the Inverse Distance Weighted (IDW) method on HIV/AIDS rates calculated at antenatal clinics, and (2) from the interpolated maps estimate or mine average HIV prevalence rates by country for each year during the decade. Through the use of GIS, this article fills a geographic gap in our understanding of the diffusion of the HIV/AIDS epidemic in southern Africa during the 1990s.

DATA AND METHODS

HIV/AIDS data came from mean HIV prevalence rates among pregnant women attending a longitudinal network of ante-natal clinics (ANCs) where HIV surveillance has been conducted from 1990-2000. The data was provided to us in the form of prevalence rates expressed as a percent. Prevalence rates are a measure of disease that allows us to determine a person's likelihood of having a disease. For example, if 300 pregnant women came to visit an antenatal clinic during the year and 100 of them tested positive for the HIV virus, then the prevalence or incidence rate at that clinic during the year would be computed as (100/300)*100 or 33%. From 1990-2000 the network of these clinics ranged from 64 to 115 (see Figure 1 for the distribution of the clinics). Data included the location (latitude and longitude coordinates) of the ANCs, allowing their mapping. HIV data collection frequency was annual from 1990-2000. Despite known limitations of such sentinel based HIV prevalence estimates (UNAIDS and WHO, 2010; Peng et al., 2011), they remain the major source of HIV prevalence rates in sub-Saharan African countries, and the only longitudinal record for analyzing the spatiotemporal trends targeted in this study without projecting to the general population or generating predictions. Nevertheless, we convert the point HIV/AIDS prevalence rates to area rates from the generated IDW smooth surface maps through the use of zonal statistics in the GIS environment. In short, in spite of the limitations involving sample representativeness and paucity of data points, ANC data are more readily available, allow longitudinal trend analysis, and can be re-scaled to national, regional, district or other scales using spatial interpolation techniques (Kalipeni and Zulu, 2008; Kalipeni and Zulu, 2012)

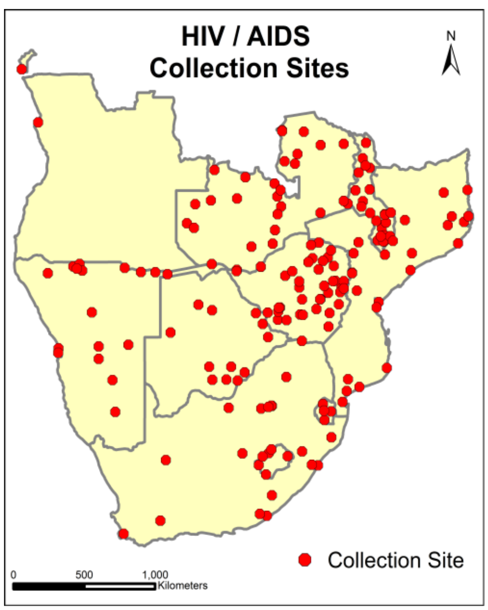

Figure 1. Antenatal surveillance data points.

In order to produce smooth surfaces of HIV prevalence for visualization and data generation at country level the Inverse Distance Weighted (IDW) spatial interpolation method was used for the selected years (1990, 1992, 1994, 1996, 1998 and 2000). These years were chosen for trend continuity with the use of the IDW technique justified given the low numbers of antenatal surveillance points that ranged from a low 64 to a high of 115 for some years. However, the data were also subjected to the kriging method to compare the mined HIV prevalence rates with those obtained from IDW. There were very minor differences between the results of the two techniques which prompted us to report the results of IDW only. Spatial interpolation methods apply mathematical models to measured point values of a continuous variable at known locations to predict values at locations that do not have values, thereby creating a continuous surface (Mitasova et al., 1995; EPA, 2004). In predicting values, interpolation methods generally use distance-based weights that assign more influence to measured values nearest an unmeasured location than to measured values located farther away. Deterministic interpolators, including IDW, use weights based only on distance between measured and unmeasured points while geostatistical (or stochastic, e.g., kriging) use sophisticated weights combining distance with probabilistic statistical models of the spatial variation among measured points. IDW produced stable and reasonably reliable predictions for cross-year comparisons with the small sample size (from 64 to 115 ANCs). It has been used reliably with small-medium samples in HIV studies (Kalipeni and Zulu, 2008; Moise and Kalipeni, 2012), at times preferred over (potentially superior) kriging whose performance often suffers more with small samples because of probability distribution requirements (EPA, 2004; Krivoruchko, 2011). With IDW, we used a variable setting of six through ten points to predict values at each unknown location based on iterative testing to minimize mean error and root mean square error (RMSE). We then used GIS tools to extract HIV estimates for the 10 countries of the southern African region by averaging prevalence values in constituent 1×1 km spatial cells.

This study uses an ecological design to examine the diffusion of HIV/AIDS. This in itself is a major limitation of the study. We did not have any information about the migrants and whether or not they in fact were responsible for HIV diffusion. However, we can infer from the analysis that this is likely the case but the analysis still cannot overstate the results from the data and the ecological study design that was used.

RESULTS: INTERPOLATED SMOOTH SURFACE MAPS

Images of the continuous smooth surface maps generated by the IDW method are given in Figure 2 and national level extraction of HIV/Prevalence rates are given in Figure 3 and Table 1. Figure 2 shows the interpolated smooth surface maps of HIV/AIDS prevalence rates, interpolated from the ANC point data for the years 1990, 1992, 1994, 1996, 1998 and 2000. To derive these interpolated rates we used the Inverse Distance Weighted (IDW) method in a GIS environment. On the other hand Figure 3 shows the HIV/AIDS prevalence rates, now averaged by country for the same six years, averaged from the Inverse Distance Weighted (IDW) maps. As noted above the national interpolated estimates of HIV/AIDS prevalence were derived by averaging prevalence for all 1-km cells in the interpolated surfaces falling within each country in the southern African region for selected years, i.e. 1990, 1994, 1998 and 2000 for demonstration purposes.

The IDW generated rates in Table 1 are indicative and only for assessing spatial patterns and temporal changes, rather than authoritative national level estimates. Nevertheless, the rates compare quite well with UNAIDS reported HIV/AIDS rates in the region as shown in the Table 1. We included the counterpart estimates of HIV/AIDS rates given by UNAIDS for the same years (1990, 1994, 1998 and 2000). With the exception of a few over-interpolated countries by the IDW method (e.g. Angola, Malawi and Mozambique in 1990, all other countries had comparable IDW interpolated values similar or close to those given by UNAIDS. To confirm our observations of the comparability of the results of the IDW technique, we conducted comparative statistical analysis using bivariate correlation analysis as well as the independent-samples Mann-Whitney U Test. For the correlation coefficient analysis the null hypothesis is that the IDW values are highly correlated with or are the same as the UNAIDS values while the null hypothesis for the Mann-Whitney U Test is that the distribution of the IDW values is the same as those of given by UNAIDS. Other similar tests such as the Kolmogorov-Smirnov Test (not shown) confirmed the findings of correlation analysis and the Mann-Whitney U Test. These tests offered confidence in our conclusion that the IDW interpolated rates compared quite well with those offered by UNAIDS during the 1990s.

The maps in Figures 2 show interpolated smooth surface maps of HIV/AIDS prevalence rates for 1990, 1992, 1994, 1996, 1998 and 2000 for the IDW method while the maps in Figure 3 summarize the results of IDW generated smooth surface maps for the same years using by country. The classifications we chose to use to display these data were in percentages as follows: 0-5, 5-10, 10-15, 15-20, 20-30, and 30 and above. We chose to use these classifications as they have been successfully used in other studies (e.g. Kalipeni and Zulu 2008) and were important to our analysis as they clearly show the intensification and diffusion of HIV/AIDS in southern Africa in the interpolated maps.

Table 1. HIV Prevalence Rates (%) from IDW (GIS) Analysis as Compared to Those Provided by UNAIDS for Selected Years

	Years							
Country	1990 IDW	1990 UNAIDS	1994 IDW	1994 UNAIDS	1998 IDW	1998 UNAIDS	2000 IDW	2000 UNAIDS
Angola	15.39	4.3	9.94	4.7	16.06	5.1	20.51	4.7
Botswana	6.07	5.4	17.73	16.7	28.59	26.6	31.36	27.9
Lesotho	1.00	1.1	11.99	10.7	26.28	24.3	22.82	25.1
Malawi	13.66	7.4	15.19	11.3	16.18	14.7	15.3	14.6
Mozambique	14.41	5.4	18.62	8.2	17.38	10.2	17.41	11.2
South Africa	1.35	1.2	9.38	5.9	19.7	15.4	22.91	18.8
Namibia	6.06	1.9	8.07	6.6	16.08	14.2	17.62	16.4
Swaziland	1.36	1.3	15.51	8.7	30.48	24.2	32.55	26.9
Zambia	18.04	13.1	17.5	17.6	16.9	17.3	28.12	16.8
Zimbabwe	18.22	15.0	26.85	27.4	26.54	31.1	35.29	29.1
Correlation Coefficient (r)*	r=0.844, p=0.002		r=0.873, p=0.001		r=0.854, p=0.002		r=0.763, p=0.010	
Mann-Whitney U Test**	p=.190		p=.165		p=.247		p=.143	

Note: *Correlation coefficient (r) indicates that the IDW generated rates are highly correlated to UNAIDS rates for the same years and same countries; **Mann-Whitney U Test indicates the distribution of the IDW generated rates versus those obtained from UNAIDS are virtually the same, i.e. they do not come from independent samples. Source: Authors, prevalence rates generated from zonal statistics in ArcGIS; UNAIDS columns from UNAIDS (2008).

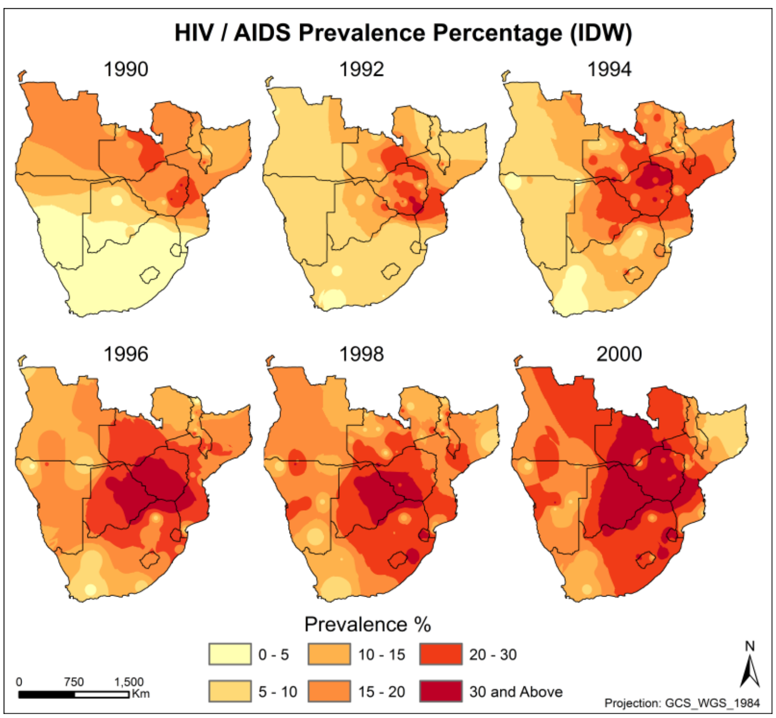

Figure 2. Interpolated smooth surface maps of HIV/AIDS prevalence rates by Inverse Distance Weighted (IDW).

Clearly these maps demonstrate the diffusion of HIV/AIDS from the north into southern countries such as Botswana, South Africa and Lesotho. By the year 2000, the epidemic had intensified in southern Africa centered on Zimbabwe and Botswana. The 1990-2000 decade saw some of the highest rates of HIV/AIDS in the world appear in this region. The extracted rates which given in Table 1 are a testament to this fact. By the year 2000 countries such as Botswana, Swaziland, and Zimbabwe had HIV prevalence rates that were above 30%. Countries with the lowest rates were Malawi (15.30%), Mozambique (17.41%), and Namibia (17.62%). The remaining countries, namely, Angola, Lesotho, South Africa, and Zambia had HIV prevalence rates that ranged from 20% to 28% for the year 2000.

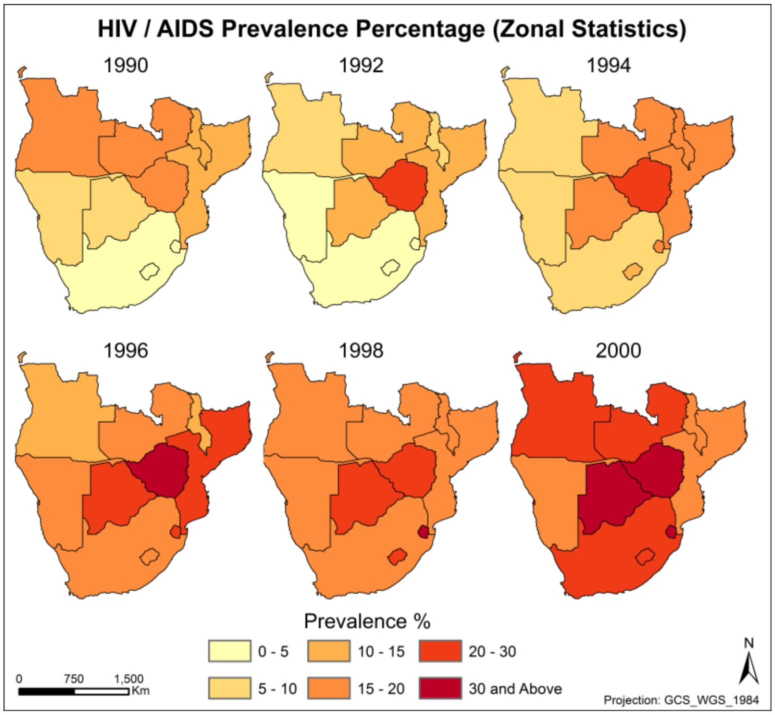

Figure 3. HIV/AIDS prevalence rates by country for 1990, 1992, 1994, 1996, 1998 and 2000 for Inverse Distance Weighted (IDW) method.

Indeed the 1990-2000 decade saw the rapid increase in terms of spatial variation throughout the region reaching a peak in 2000. All ten countries in the region showed an increasing trend over the period. Figure 4 clearly illustrates the rapidly increasing trend in four selected countries of Zimbabwe, Botswana, South Africa and Swaziland. Figure 2 also points to the fact that most of the initial prevalence increases were in the northern countries of Malawi and Zambia. Over time during the 1990s decade the HIV rapidly diffused southwards and intensified as it spread. The central question is why did HIV/AIDS find fertile ground in southern Africa to spread so fast and to continue to stay at high levels even today? To answer this question we draw upon the unique historical context of Africa as an explanation for the spatiotemporal trends southern Africa experienced.

EXPLAINING THE DIFFUSION OF HIV/AIDS IN SOUTHERN AFRICA

The high prevalence of HIV/AIDS in southern Africa as shown in Figures 2 & 3, including its progression in space and over time is strongly related to the interconnectedness of the physical environment, history and international labor migration (Yeboah, 2007; Kalipeni et al. 2007). Because of the excellent climate in eastern and southern Africa conducive to European settlement, rich soils, presence of numerous minerals (gold and diamonds among them) and other resources, Europeans came to settle to this part of Africa in contrast to tropical West Africa. In doing so, they established "Islands of Economic Development", setting in motion massive movements of labor from rural areas to resource rich areas, locally as in the case of Zambia and internationally as in the case of South

Africa (see Figure 5 for the Islands of Development). The intermixing of peoples on a grand scale meant also the spread of various diseases from one part to another, particularly sexually transmitted diseases.

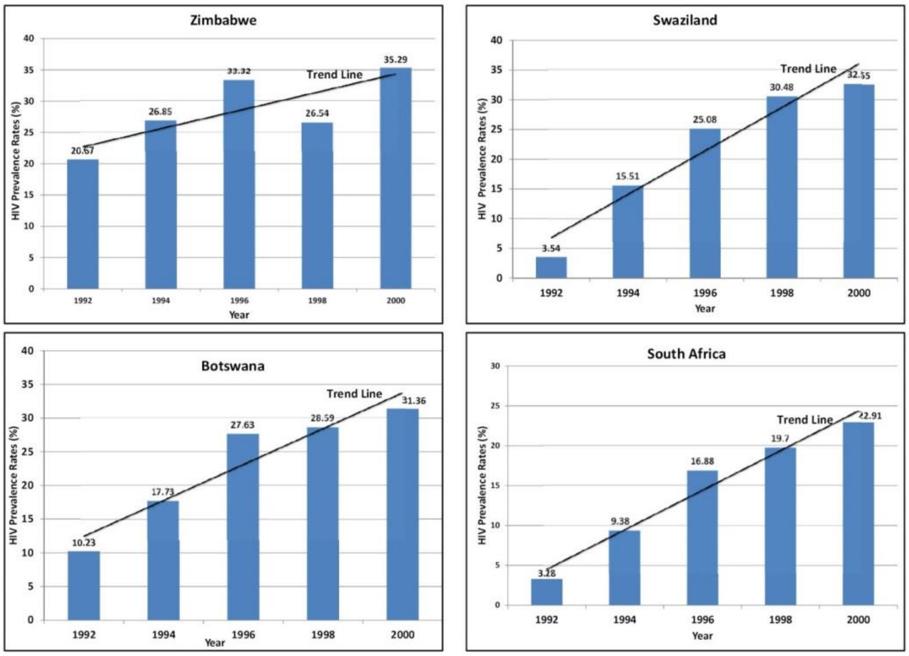

Figure 4. IDW generated HIV prevalence rates from 1990-2000 for selected countries.

Two excellent examples stand out, i.e. Zambia and South Africa. The high prevalence and incidence rates of HIV/AIDS in Zambia are concentrated in the copper belt of the country. With the arrival of the first Europeans in 1850 and the eventual introduction of colonialism in 1890, population movements in Zambia took another dimension. Prior to the governance by the British Colonial Office, Zambia (then Northern Rhodesia) was ruled by the British South Africa Company (BSAC), which employed a variety of tactical measures such as imposing hut tax designed to encourage labor migration, first to the mines of South Africa, and later to the emerging mines on Northern Rhodesia's (Zambia's) own Copperbelt province (Simatele, 2007; Macwangi et al., 1996; Chilivumbo and Mijere, 1994).

Macwangi et al. (1996) observes that the mechanisms on which such migration encouragements were based involved the imposition of hut and poll taxes on very grown up male, failure to which harsh jail sentences and punishment were administered. Such measures had negative impacts on the traditional livelihood systems of many rural populations and also limited the room for them to adopt other rural livelihood options. Several scholars have argued that leaving their home communities to work in the mines of South Africa, the Katanga province of the Democratic Republic, or the Copperbelt province of Zambia was not an option that men chose with pleasure; but it was simply how people coped with the given circumstances (Macwangi et al, 1996; Chilivumbo & Mijere, 1994). We can therefore conclude with confidence that the colonial period is an important period to consider when studying migration dynamics in Zambia. It is important to note that it is this period that lay the foundation for future population movements that came to be manifested in the post-independent period (see for example Figure 6). The colonial era not only triggered internal movements but also international or cross-border movements such as those directed to the cold mines of South Africa (Simatele, 2007).

Another example of the lingering impact of colonial rule and its economy is South Africa. This country has a long history of political unrest as well as racial and social tensions. The legacy of colonization and apartheid includes a large population of economically disenfranchised people. During apartheid the black population, which comprised 80 % of the total population, was forced to live on only 13 % of the total land area of South Africa. Much of this land was environmentally marginal, of poor quality for agricultural purposes, and lacked any meaningful resources to form viable livelihoods for the black population of South Africa (Desmond, 2001; van Niekerk, 2001). This lack of economic prospect has forced many black people to migrate on a seasonal basis to towns, cities and mining areas.

With the end of apartheid over two decades ago, South Africa has emerged as a leading economic power, but continues to struggle with the economic marginalization of selected population groups. This struggle has indirectly contributed not only to South Africa's rapid increase in HIV/AIDS cases but also to the challenges facing the country in combating the epidemic.

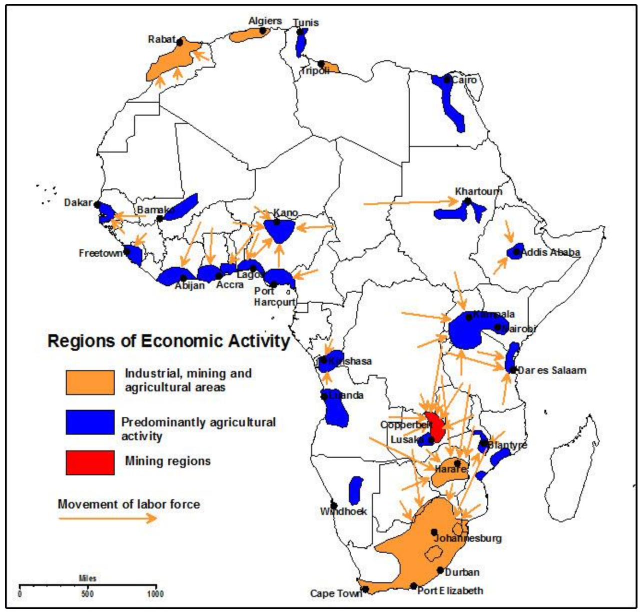

Figure 5. Islands of economic development in Africa.
Source: Adapted from Martin & O'Meara (1986)

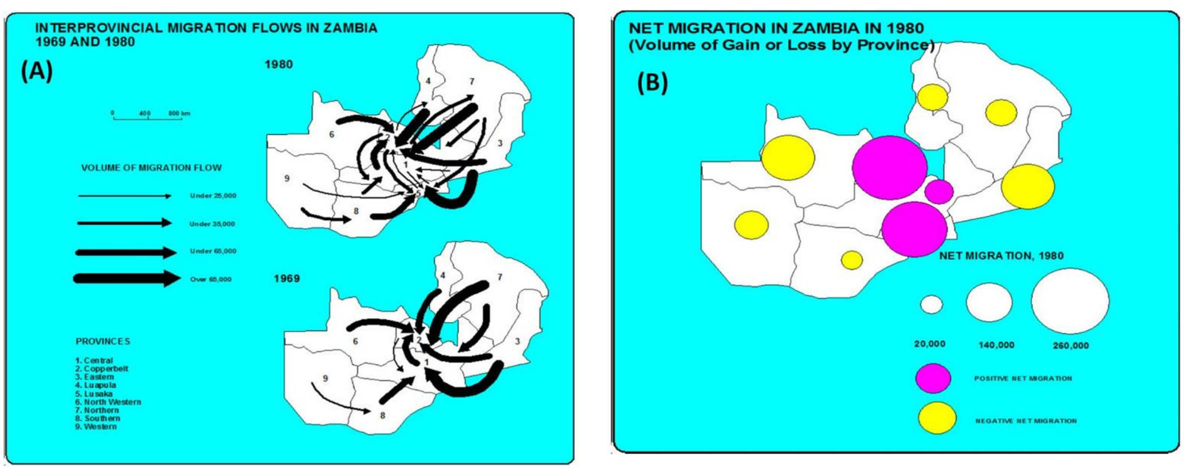

Figure 6. Migration flows in Zambia in 1980. Source: Adapted from Chilibvumbo and Mijere (1994)

The major economic factor contributing to the rapid spread of HIV/AIDS in South Africa is migrant labor. This includes foreign migrant workers, rural to urban migrants, truck drivers, young women, and mine workers (see Figure 7A). Because of the dearth of job opportunities and very low incomes in rural areas, many heads of households, mainly young men, are forced to migrate to urban areas in order to find employment. It is generally assumed that when young men leave rural homes in search of work in urban areas, they may engage in sex with other women at areas of destination, putting the women or themselves at risk of infection. Prolonged separation from their wives encourages miners to have sexual relationships with other women and, for that matter, other men. When they return to their rural homes, those infected with HIV infect their rural partners as well. This circular migration is typical of the patterns of movement of young men and women throughout southern Africa (Horwitz, 2001; Campbell, 1997).

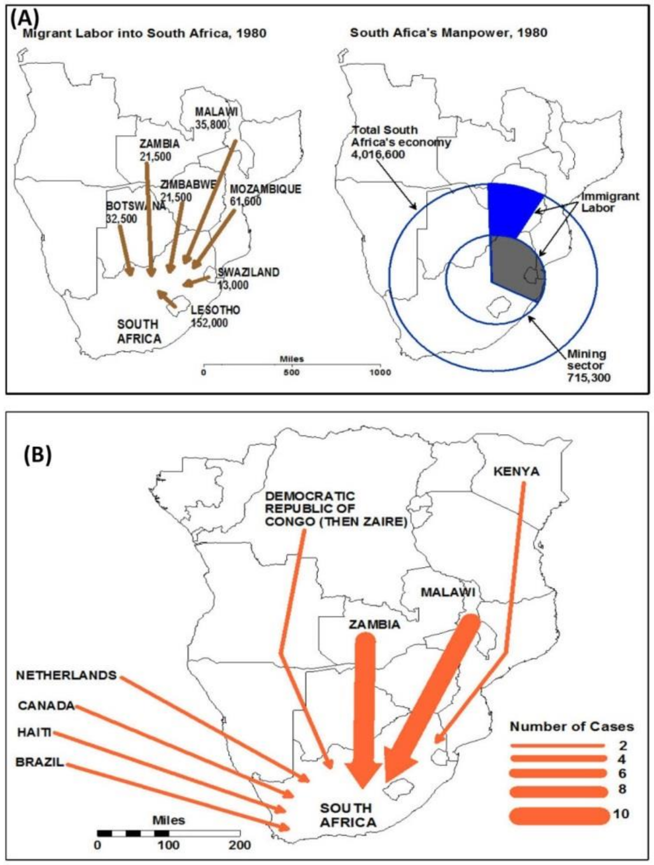

Figure 7. Migration and Introduction of HIV/AIDS in South Africa: (A) source countries of migrant labor into South Africa and South Africa's total manpower in 1980, (B) Nationality of alien AIDS cases in South Africa by November 1988; Source: Figure 5A adapted from Griffiths (1984); Figure 5B adapted from Smallman-Raynor et al. (1992). Note: Arrow widths indicate the number of cases originating from each country.

A substantial amount of research has also focused on the role of truck drivers in southern and eastern Africa as a major player in the rapid spread of HIV/AIDS (Bwayo, 1994; Mbugua et al., 1995; Marcus, 2001). In short, the colonial economy that was introduced in southern and eastern Africa during colonial rule has fostered a fertile environment in which men and women find themselves vulnerable to the rapid spread of HIV. Smallman-Raynor et al. (1992) noted that the first cases of HIV/AIDS in South Africa were introduced in 1988 by several aliens that had migrated to South Africa while already infected with the virus (see Figure 7B above for the nationality of the alien AIDS cases).

STUDY LIMITATIONS

This study has several shortcomings which might undermine the credibility of the spatial analysis. For example, the interpolation and aggregation methods used might obscure the data rather than provide clarity in terms of clearly demonstrating the diffusion of HIV/AIDS in southern Africa over time, the central hypothesis the authors are attempting to prove. Simpler methods such as mean center and standard deviational ellipses derived from the a consistent set of antenatal clinics would probably have provided more support for the diffusion hypothesis. Unfortunately, such data consistent data was not available from year to year as the antenatal clinics that collected the pertinent data kept changing from country to country and from year to year. Another weakness is the lack of incorporation of population densities in the aggregation technique and the relative uncertainty associated with incidence rates at the antenatal clinics. However, the strength of the analysis contained in this paper lies in its visual inspection of maps, an important spatial analysis tool. Furthermore, the paper demonstrated that the mined data from the results of spatial interpolation, in spite of a few outliers, was comparable to the statistics or rates given by UNAIDS during the 1990s decade. It is therefore important to note that the results of the analysis in this paper should be used as a starting point for more in depth analysis should more reliable data become available. The results should be treated as exploratory and indicative of the situation in the spread of HIV/AIDS in southern Africa during the 1990s decade.

CONCLUSION

The first part of this paper created interpolated smooth surface maps of HIV/AIDS prevalence rates. These were calculated from HIV/AIDS rates obtained from a set of antenatal clinics from pregnant women throughout the southern African region. The maps which show spatiotemporal trends and the diffusion of HIV/AIDS throughout the rest of the region were generated using the Inverse Distance Weighted (IDW) in a GIS environment. Secondly, average HIV/AIDS rates were calculated from the smooth surface maps and mined using the zonal statistics tool in ArcGIS for the selected set of years. Both the maps and the average HIV/AIDS rates show a rapidly increasing trend in the diffusion and the intensity of the disease in southern Africa. The last part of the paper discusses the role of migration in the spread and intensification of the pandemic in this region. The unique forms of migration flows introduced during the colonial era are blamed for the rapid spread and intensification of HIV. In spite of our argument about the role of migration in the spread of HIV/AIDS in this region, we would like to note that migration is an enabling vehicle that resulted in the rapid diffusion. There are other equally potent dimensions that have contributed significantly to the spread. For example, Kalipeni et al. (2007) offer an explanatory model of these other factors which include the burden of poverty and other diseases, global and local government commitment, the cultural context, the gender context, and political instability. These and others require a careful consideration. However, the colonial migration system should be viewed as the umbrella dimension when considering these other factors.

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