

## **A FRACTAL APPROACH TO THE EPIDEMIOLOGY OF HUMAN IMMUNODEFICIENCY VIRUS**

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### **ABSTRACT**

*This paper examines the documented HIV cases around the world as reported by the United Nations in 2012. A fractal analysis was performed to develop an epidemiologic model for the spread of HIV infection. As revealed the reported HIV cases do not follow a fractal model, rather, the logarithmic data transformation showed a lognormal distribution. The epidemiologic model developed assumed a normal distribution on the logarithm of the data and therefore, the spread of the disease is modeled as a Brownian motion with two (2) centers. The first center of the Brownian model is located at the original "origin" of the disease in Africa, while the second center is located in a Latin American country. The two (2) Brownian processes will eventually intersect thereby accelerating the spread of the disease. Both active and passive intervention strategies are discussed to halt the spread of the disease globally. The two (2) fundamental reasons which facilitate the spread of the disease are (a) migration of workers due to national economic constraints, and (b.) social and cultural stigma attached to the disease.*

**Keywords:** epidemiologic model, HIV, Brownian motion, fractal analysis

### **Introduction**

Human Immunodeficiency Virus (HIV), the virus that causes Acquired Immunodeficiency Syndrome (AIDS), is one of the leading causes of death worldwide. This disease is sexually transmitted and has an impact on the family, community, and eventually to the nation's economic development. The incidence rate of AIDS is noted to be high among the less developed countries because of poor social services and low education. The spread of the disease is facilitated by having unprotected sex, sharing of infected drug needles and other such poor health practices which characterize most underdeveloped and developing nations. Once infected, an individual can transmit the disease unknowingly such as what happens to mothers who are HIV positive and breastfeeding their young. While the mode of transmission of the disease is well-established, research on the epidemiology of HIV remains active. This paper attempts to analyze the incidence of HIV globally

in the hope of discovering some hidden dimensions in its epidemiological characteristics. The fractal analysis provides a convenient platform through which such an analysis may be done.

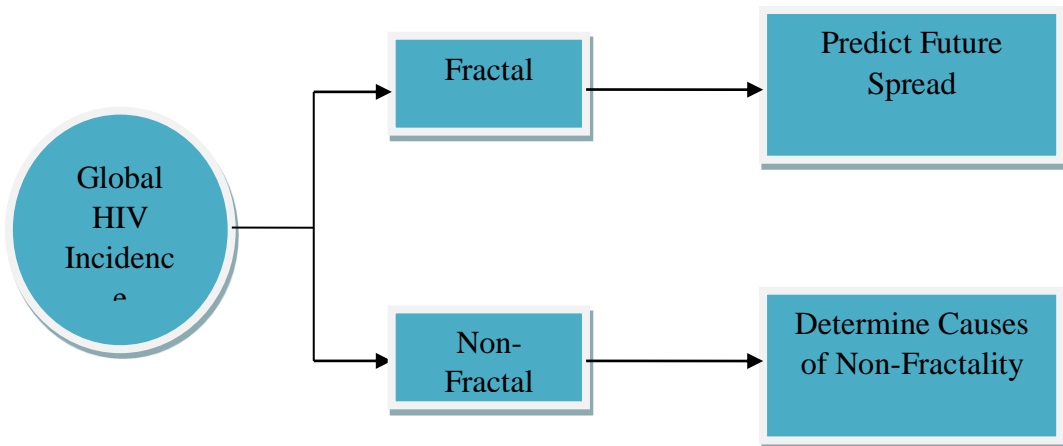
The statistical literature on HIV contains important information which can be used in in-depth studies. For instance, it is known that Sub-Saharan Africa is the most affected region, with 24.7 million people living with HIV in 2013. Also, sub-Saharan Africa accounts for almost seventy percent (70%) of the global total of new HIV cases (WHO, 2014). Furthermore, Beegle, K., and D. de Walque, (2009) confirmed this information in their study on the “Demographic and Socioeconomic Patterns of HIV/AIDS Prevalence in Africa”. Meanwhile, Medlin, C. and D. de Walque (2008) conducted a study on “Potential applications of conditional cash transfers for prevention of sexually transmitted infections and HIV in Sub-Saharan Africa”, Two studies of de Walque, D. and R. Kline (2006, 2009) on “Comparing condom use with different types of partners: evidence from national HIV surveys in Africa” and “The association between remarriage and HIV infection: evidence from national HIV surveys in Africa”, determined the most effective solution to promote the prevention or even stop the transmission of this infectious disease. Studies are also conducted worldwide to determine the factors that affect the transmission of HIV. One of these is the study of de Walque, D., (2009) on "Does Education Affect HIV Status? Evidence from five African Countries" and found out that education is not positively associated with HIV status. However, schooling is one of the most consistent predictors of behavior and knowledge: education level predicts protective behaviors such as condom use, use of counseling and testing, discussion of AIDS between spouses, and knowledge about HIV/AIDS, but it also predicts a higher level of infidelity and a lower level of abstinence.

The studies reviewed revealed some interesting aspects in the spread of HIV across geographic locations. It is noted that the analyses performed were mainly “wholesale” describing the general typical characteristics of the individuals prone to HIV infection. The smaller and localized characteristics of the individuals are, therefore, masked in the process: largely subsumed by the “average” or typical characteristics. A fractal approach to the same problem can be useful in the sense of determining the smaller and localized characteristics of HIV-infected individuals eventually leading to their larger “average” behavior manifested at the regional and sub-regional levels. This study aims to examine these localized fluctuations and variations in the spread of HIV infection across the globe.

## **Conceptual Framework**

The study rests on the foundations of the new science of Fractals (Mandelbrot, 1982) and of Fractal Statistical Analysis (Padua, 2014). Fractal observations are characterized by the preponderance of smaller values than larger values. For instance, it is more likely to observe several countries having smaller Gross Domestic Products (GDP) than countries having larger GDP i.e. there are more underdeveloped and developing countries than highly developed countries in the world. Mandelbrot (1987) argued that “nature is fractal” and that such a reality had been largely ignored in the past. The natural state of things in the world is fractal and the farther we are from this natural state, the smoother becomes the observations. There are two (2) extreme ways in which departure from fractality can be achieved through man’s intervention. First, the observed values may be adjusted upwards so that higher values become more frequent. For example, economic integration of national economies e.g. the European Union, ASEAN integration, is a prime example of a man-made attempt to destroy the natural state of the distribution of GDP’s because smaller economies become integrated into the much larger integrated economy. Second, the observed values may also be adjusted downwards so that the range of values become bounded i.e. extreme values are eliminated. For example, during disasters, there are significantly smaller damages incurred than larger damages in a given locality. Disaster-preparedness and risk-mitigation strategies had been put in place to eliminate the possibility of incurring larger damages in the future. Through these strategies, the natural fractality of the estimated typhoon-caused damages is destroyed.

From these fundamental principles of fractal analysis, we argue that the “incidence rate of HIV infection across the globe began as a fractal phenomenon and have evolved to its present state of the non-fractal phenomenon through various interventions made to halt the spread of the disease”. Armed with this principle, we propose to examine the causes of non-fractality and thereby produce policies that appear to have been effective in reducing the original fractal state of the HIV spread across the world. This conceptual framework is schematically represented below:



**Figure 1.** Schematic Diagram of the Conceptual Framework

## Methods

The study made use of the descriptive method of research by employing the techniques of fractal analysis. Data for the incidence of the HIV infection were obtained from UNAID (2013 Report) available electronically from this website. A total of 101 countries spread across the various continents had submitted their reports to the organization responsible for monitoring the spread of the disease.

The fractal methodology begins by determining an approximate histogram of the HIV incidence rates. The histogram will show if the concentration of the values is in the lower or upper scales. If there is sufficient evidence to deduce that there are smaller values than larger values in the data set, the analysis proceeds by obtaining the logarithm of the quantities (data/minimum data). The histogram of the transformed data ( $\log(\text{data})$ ) is then determined. If the histogram shows characteristics of an exponential distribution, then the original data is declared as fractal otherwise, they are non-fractal.

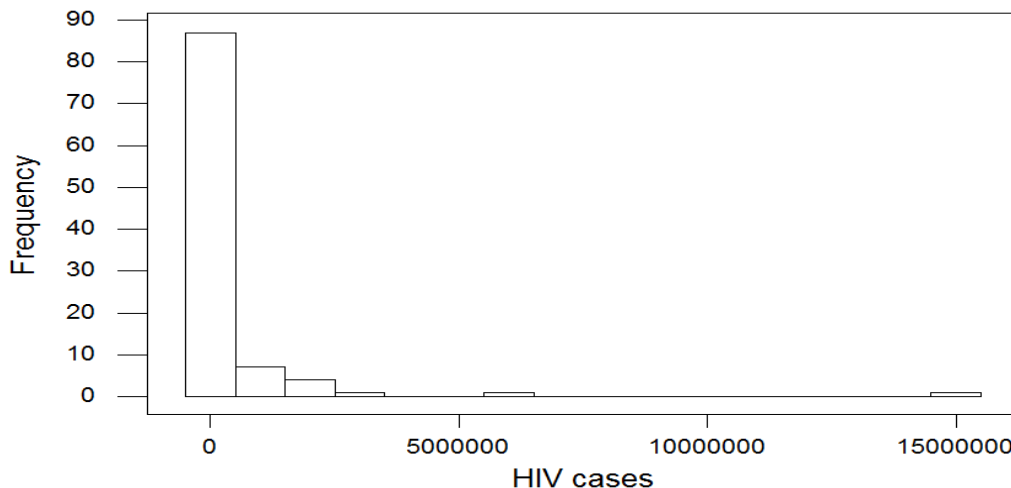
If the fractality test shows that the original data are fractal, then the logarithm of the data can be used to determine the probability that the HIV infectives are between two values. Likewise, the logarithm of the data can be used to surmise the survival function ( $1 - F(x)$ ) and as predictors of “inter-arrival times” (times between successive infections).

On the other hand, if the fractality test shows that the original data are non-fractal, then one can hunt for the observations that caused the non-fractality and from these observations deduce the reasons for the current non-

fractal behavior of the data set. The fractal dimension of the data determines the number of possible reasons for the non-fractality.

### Results and Discussion

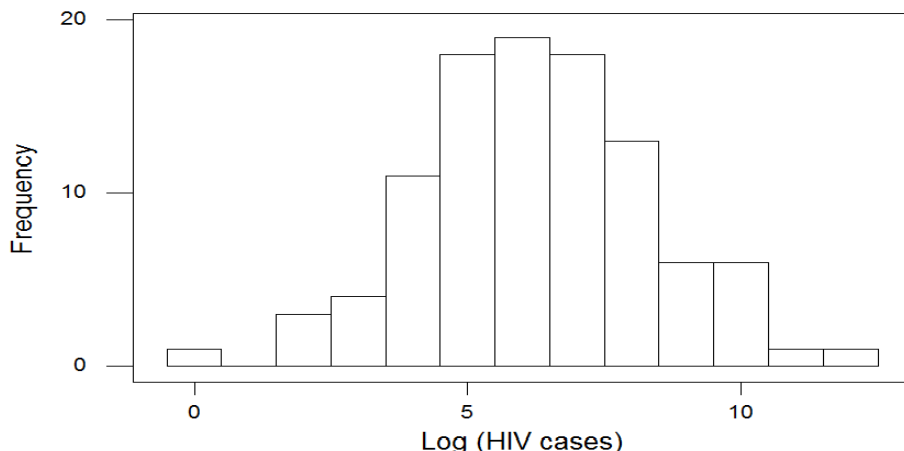
Figure 2 shows the histogram of the original observations on the estimated number of HIV cases in 101 countries across the globe.



**Figure 2.** Histogram of the HIV Cases across 101 countries (2012)

The histogram confirms the hypothesis that there are more countries with low counts of HIV cases than countries with higher HIV case countries. However, because the tail of the probability distribution appears to taper off in an exponential manner, we suspect that HIV cases is not exactly fractal but is slightly different from the natural state.

Figure 3 shows the histogram of the logarithm of the data to test the fractality of the observations.



**Figure 3.** Histogram of the Logarithm of HIV Cases (2012)

The histogram of the logarithm of the HIV cases across the world appears to be normally distributed which is confirmed by a Kolmogorov-Smirnov test ( $p < .05$ ). This situation implies that the spread of HIV infection across the world appears to have sufficiently diffused in an essentially Brownian manner. The phenomenon of observed HIV cases has already departed from the natural state (from the origin of the disease to its spread in nearby countries).

The histogram further suggests that countries belonging to the lower half of the histogram account for the observed non-fractality of the current observations. The fractal dimension calculated amounted to 1.16049 which means that there are least two (2) reasons which can be discovered from an analysis of the countries in the lower half of the histogram.

**Common Characteristics of the Countries in the Lower Half of the Histogram.**

Countries that belong to the lower half of the histogram are those which have relatively fewer reported cases of HIV (26,000 or lower cases) and have just recently reported the first few cases of HIV in their countries i.e. new infectives. These consist mainly of underdeveloped or developing countries whose migrant workers have little or no record of having worked at the origin(s) countries of HIV viz. South Africa and Nigeria. The Philippines belong to this category of countries with a reported 15,000 HIV cases. Latin American countries like Honduras, El Salvador, Paraguay, and Uruguay

share some social and cultural similarities that explain their being grouped in the same lower half of the histogram.

Historically, Philippine migrant workers have opted to work offshore in countries like the United States, those in the Middle East and parts of Europe with a very small number of workers in the African countries where the first HIV case was reported. As the disease spread through parts of the African countries and portions of the Middle East, the 1997 economic crisis forced many of the migrant workers to shift their work destinations to these countries as well. Upon return to their countries of origin, some of the migrant workers may have inevitably contracted the disease.

The state of underdevelopment or development of the countries where these migrant workers came from had facilitated the spread of the infection. Poor social services, lack of education, and the societal stigma attached to the disease have worked in perverse combination to facilitate the fast spread of the infection at the national level.

### **Epidemiological Model for the Spread of HIV Cases**

Knowing that the HIV cases across the different countries in the world no longer follow a fractal distribution but a log-normal distribution, we now attempt to define a model for the spread of the disease.

The original 101 countries analyzed produced a log-normal distribution (the logarithm of the data is normal) whose mean is  $\mu = 6.231$  and standard deviation of  $\sigma = 2.094$  while the forty (40) countries which formed the lower half of the histogram of the lognormal distribution had a mean of  $\mu_1 = 4.240$  and standard deviation of  $\sigma_1 = 1.149$ . The countries forming part of the lower half of the histogram can be considered as “new origins” of the disease in their parts of the globe with spread pattern following a Brownian motion with a drift or spread coefficient of 1.149 (in logarithmic scale). Meanwhile, the original upper half of the histogram where the original “origin” of the disease is found will continue to spread the disease in the same Brownian pattern with a spread or drift coefficient of 2.094 (in logarithmic scale). This means that ultimately, the two Brownian paths will intersect and the spread of the disease will be accelerated unless more aggressive global interventions are adopted to halt the spread of the disease.

Interventions such as education and information campaign about AIDS when adopted as part of the educational experiences of the citizens may partly slow down the spread of HIV infection. However, a more active

intervention such as requiring HIV-testing for all migrant workers going out or getting into the countries and then establishing a government-assisted AIDS support system for patients diagnosed with the disease will more effectively curb the unfettered spread of the infection globally.

## **Conclusion**

The reported HIV cases as of 2012 no longer follow the natural state or fractal state in the sense that it has progressed to become a global problem. The spread pattern of the HIV infection across the globe follow a lognormal distribution which means that the new entrants or countries with more recent first reported HIV cases become the new “origins” of the disease with a spread pattern following a typical Brownian motion. Both passive and active interventions by government and non-government organizations are required to halt the spread of the disease before it accelerates as predicted by an epidemiologic model in this study.

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