Bima Journal of Science and Technology, Vol. 8(2) June, 2024 ISSN: 2536-6041

DOI: 10.56892/bima.v8i2.659

Computational Model for HIV with Syphilis Infection in Women Characterized by Poverty, Gender and Relationship Dynamics

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ABSTRACT

In sub-Saharan Africa, the number of new HIV infections by age and sex is rising daily. One-third of women between the ages of 15 and 24 years lack thorough awareness about HIV and co-infection, particularly in rural regions. Relationship dynamics, gender inequality, poverty, and other social, economic, and fundamental factors contribute to the high susceptibility rate. Women living with HIV and co-infection confront unique problems. In order to comprehend the underlying dynamics of HIV and co-infection, there are still significant gaps in the quantity and quality of STD-related information that is currently accessible in Nigeria. In this paper, we offer a computational model of the dynamics of HIV with syphilis transmission in Nigeria, where relationship dynamics, gender inequality, poverty, and other social, economic, and fundamental factors are the main causes of HIV and co-infection in females, as seen from the results. Therefore, spreading the preventative message is crucial to reducing or eliminating this threat in Nigeria. From the results obtained, the model has provided a clear understanding of how to eradicate the diseases and shows that, with combined efforts from the government and individual citizens, HIV and co-infection can be lowered, if not completely eradicated, to the lowest possible level among women in the 15-24 age range. This study will be very helpful to the Nigerian government and people in tackling poverty and the effects of actions on women between the ages of 15 and 24 years. On the other hand, the combined effort of government and individuals can help reduce STDs at every level, and girl-child education will be promoted.

Keywords: Model, Infection, Co-infection, Relationship & Dynamics

INTRODUCTION

The rates and patterns of sexual activity will have a significant impact on the spread of co-infection and the Human Immunodeficiency Virus (HIV) to the global populace (World Health Organization [WHO], 2020). Young individuals (15–24 years old) account for almost half of all new infections that arise each year, making them more susceptible to STDs than older persons because:

i. Young people's cerovaxic (the passageway between the vagina and the womb) coated with cells more susceptible to STDs

ii. Young adults and teenagers may struggle to receive the resources and information they need to stay away from STDs.

iii. Could be concerned about privacy

Furthermore, due to some variables, including higher rates of poverty, less access to healthcare, and an already high prevalence of STDs in their communities, teenage girls and women have some of the highest rates of STDs, particularly syphilis. Annual screening is advised for all sexually active women under 25 and for older women who have recently or frequently partnered (The Well Project, 2021).

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The Human Immunodeficiency Virus (HIV) was first discovered in west-central Africa in the late 19th and early 20th centuries. The early 1980s saw the discovery and recognition of HIV. HIV is a virus that gradually weakens the body's natural protection against disease, the immune system. The virus eliminates a subset of white blood cells known as CD4+ T-lymphocytes (CD4) cells. HIV comes in a variety of forms. The two primary categories are HIV-1, which is the most prevalent variety globally, and HIV-2, which is primarily found in Western Africa, with a small number of infections also occurring in India and Europe. The virus is transferred from one person to another through sexual contact and blood-to-blood contact. Other means of bodily fluids from an infected person that contain HIV are semen and vaginal secretions, blood, and breast milk. Furthermore, pregnant HIV-positive mothers have the potential to transmit the virus to their unborn children (Nigeria Galleria, 2021).

The virus responsible for Acquire Immunodeficiency Virus (AIDS) is called HIV. HIV testing is a standard medical care component in many nations, including Nigeria. If a person has ever shared needles, engaged in unprotected sexual activity, is not sure of their partner's HIV status, or has ever had an STD diagnosis, they must get tested. HIV can cause severe sickness that can be serious if left untreated. Effective treatment aids those living with the virus to live better when treated to the point of undetectable viral load (The Well Project, 2021).

According to the first-ever consensus statement, which was created in 2008 by a group of Swiss scientists, an individual living with HIV who is receiving effective antiretroviral therapy, has an undetectable viral load, is free of sexually transmitted infections has little chance of spreading the virus to others (HealthLine, 2020). Their conclusion was based on research showing that an appropriate treatment plan can prevent HIV transmission from one HIV-positive partner to an HIV-negative partner.

Poor public health services and socioeconomic conditions are often cited as the primary causes of the HIV pandemic in Nigeria. These include inadequate access to high-quality healthcare services, poverty, harmful peer pressure, and a lack of or insufficient public health education and counseling regarding safer sexual behaviors (Garba & Gumel, 2010).

Treponema pallidum is the bacteria that causes syphilis. Primary syphilis, which usually manifests a few weeks to months after infection, is the first stage of the disease. Genital sores or lesions are typically seen at the anatomical location where the bacteria first entered the body in cases of primary syphilis. Skin rashes and mucous membrane lesions (sores), or both at a site or sites away from the initial lesion, are the hallmarks of secondary syphilis (CDC fact sheet, 2020). It may progress to tertiary syphilis, the most advanced stage of the disease, due to a lack of identification, treatment, and or prompt care after a period of latency (during which there are no visible signs or symptoms). Although rare, tertiary syphilis can impact many organ systems, such as the liver, blood vessels, brain, nerves, eyes, heart, bones, and joints (CDC fact sheet, 2020).

On the other hand, ocular and neurologic syphilis might manifest at any point in the illness. When a pregnant mother transmits the infection to her fetus during pregnancy, it results in congenital syphilis. Even though syphilis is treatable, untreated syphilis increases the chance of HIV infection. Preterm birth, stillbirth, and newborn mortality are all possible outcomes of

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congenital syphilis. Left untreated, It can be fatal (CDC fact sheet, 2020).

Asekun-Olarinmoye and Olajide (2011) claim that HIV spreads most quickly and widely among persons living in poverty, helplessness, and conditions that many young people, particularly those in rural regions, experience.

To better grasp the underlying dynamics of the diseases and their expected future course, there are still significant gaps in the quantity and quality of information on HIV and syphilis that is currently available in Nigeria. Specifically, information that sheds light on the origins of novel viral infections. To what extent are the existing responses effectively tackling emerging viral infections?

According to a study by Mark (2020), STDs like syphilis and gonorrhea not only make it easier for HIV to enter the body's sensitive cells and tissues, but they also basically make an infected person more contagious, increasing the likelihood that they would spread the virus to other people.

In order to understand the transmission dynamics and management of certain STDs, such as HIV and syphilis, different control strategies are targeted at figuring out potential means of spreading these diseases need to be evaluated; this is because scenarios can be computationally modeled. Long-term success can only be attained by improving understanding through a model of the populace and equipping them with skills towards knowledge that stop the spread of HIV and syphilis.

Related work

Various models have been designed and implemented to study the impact of control strategies on the spread of STDs in given populations. Some of these studies have shown that a change in risky behaviour is necessary to prevent, even in the presence of a vaccine and/or treatment (Ishaku et al., 2020). Some studies tend to emphasize on the use of pharmaceutical interventions such as vaccine, which is not readily available for example in resource poor nations like Nigeria.

Oladotun, and Suares, (2016) study a mathematical model with two control variables, where the uninfected CD4+T cells follow the logistic growth function and the incidence term is saturated with free virions. As a result of protection measures being used by the HIV patient, variant model was obtained using the Gauss-Seidel-like implicit finite difference method which was developed in 2001. The limitation of their model is that, they did not take into consideration effects associated with excessive use of drug, cost of treatment. Although their results could be useful in developing improved treatment regimen towards addressing the challenge of HIV/AIDS.

Omondi et al., (2019), studied mathematical compartmental models of HIV transmission within and between two age groups in Kenya. They fitted the model to data using Markov Chain Monte Carlo (MCMC) technique and inferred the parameters. Estimation of their basic reproduction numbers within age group transmission and between age groups transmission. The analysis of the data revealed that there is significant difference in mean number of new HIV infections between males and females within the two age groups. More, particularly, females are highly infected with HIV as compared to their male counterparts. Their findings can be used to educate the young adults on practicing safe sex with their partners in order to contain the occurrence of new infections and thereby captures Abstinence.

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Difference approaches in responding to STDs especially virus and bacteria diseases with different types of models were reviewed with their limitations and similarities to computation model. Model is urgently needed for health related problems an understanding to this model would be of important help as it will serve as an indicator in determining special behaviours in young adult in order to predict future under different conditions of the population. Sixteen percent of young girls (ages 15 to 19) in Sub-Saharan Africa are said to have had sex before fifteen. Compared to children orphaned by other causes, children orphaned by STDs are more likely to experience exploitation, abuse, progressive issues, and disease (Abiodun, 2012). Significant social issues have been brought about by HIV and co-infection in the community, including a sharp decline in life expectancy, an increase in deaths, particularly among the working population, a daily rise in the number of orphans, and detrimental socioeconomic effects on households and the country as a whole (Kimberly & Gail, 2015). Therefore, studying the population and the impact of preventive actions in a controlled setting is very necessary.

MATERIALS AND METHODS

The schematic diagram in Figure 1 describes the movement of individuals from one community to another. The total population $N(t)$, at time *t*, is subdivided into six (6) compartments, thus: susceptible individuals $(S(t))$, HIV infected unaware of their status, $(H_u(t))$, HIV infected aware of their status, $(H_a(t))$, HIV with syphilis unaware of their status,($H_s(t))$, HIV with syphilis aware of their status, $(H_b(t))$, HIV with syphilis aware of their status and receive treatment, $(H_x(t))$. Hence;

$$N(t) = S(t) + H_u(t) + H_a(t) + H_s(t) + H_b(t) + H_x(t) \qquad (1)$$

Change in the susceptible $(S(t))$ at the time (t) is the number of birth rate (inflow) minus the number of deaths; individuals are recruited into the HIV pool yet unaware.

Change in HIV-infected persons unaware of their status (H_u) at the time (t) is the rate at which susceptible individuals are recruited into the infected pool unaware and the rate of HIV infected becoming aware of their status.

Change in HIV-infected persons who are aware of their status (H_a) at the time (t) is the rate at which HIV-unaware individuals become aware of their status minus their death rate and the rate at which HIV-infected persons become infected with syphilis yet unaware of the infection.

Changes in HIV infected person with syphilis unaware of their status (H_s) at time (t) is the rate at which the HIV-infected individuals are unaware of syphilis infection minus their death rate and the rate at which they now become aware of their infection with syphilis.

Changes in HIV infected person with syphilis aware of their status H_b at time (t) is the rate at which HIV infected with syphilis, unaware of their status, now becomes aware minus their death rates and rates at which they get treatment.

Changes in HIV infected person with syphilis aware of their status and receiving treatment H_x at time (t) is the rate at which HIV-infected syphilis people get treatment minus their death rate. This indicates a rising trend in individuals seeking and receiving treatment after becoming aware of their co-infections.

$N(t)$ serves as a valuable record of the changing total population over the specified period attributed to socioeconomic factors, environmental influences, and shifts in population dynamics. The flow diagram in

Bima Journal of Science and Technology, Vol. 8(2) June, 2024 ISSN: 2536-6041

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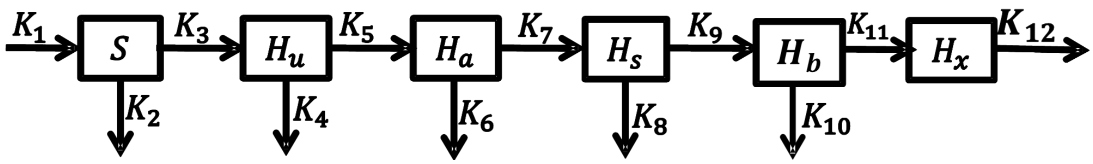
Figure 1 was used to derive the model equations.



Where

$k_1 =$ birth rate of susceptible persons;

$k_2 =$ death rate of susceptible persons;

$k_3 =$ rate of susceptible persons infected with HIV unaware;

$k_4 =$ death rate of HIV infected persons unaware of thier status;

$k_5 =$ rate of HIV infected unaware persons becoming aware of thier status;

$k_6 =$ death rate HIV infected persons aware of thier status;

$k_7 =$ rate at which HIV infected aware persons are infected with syphilis yet not aware;

$k_8 =$ death rate of HIV-infected with syphilis unaware persons;

$k_9 =$ rate at which HIV-infected with syphilis unaware persons become aware of their syphilis status;

$k_{10} =$ death rate of HIV-infected with syphilis aware of thier persons;

$k_{11} =$ rate at which HIV-infected with syphilis aware persons are recieving treatment ;

$k_{12} =$ death rate of HIV-infected with syphilis aware persons on treatment;

Figure 2 below is the algorithm of the computational frame work. The actuity diagram illustrates the computational framework in steps where each paramter is executed accordingly.

Table 1: Variable description and initial values from Ishaku *et al*. (2020) and AHNI (2023)

Parameter	Initial Condition	References
S	41,011,622	Ishaku *et al*., 2020
H_u	1,212,610	Ishaku *et al*., 2020
H_a	212,261	Ishaku *et al*., 2020
H_s	1,480	AHN., 2023
H_b	640	AHN., 2023
H_x	530	AHN., 2023
N	42,439,143	Total population estimated

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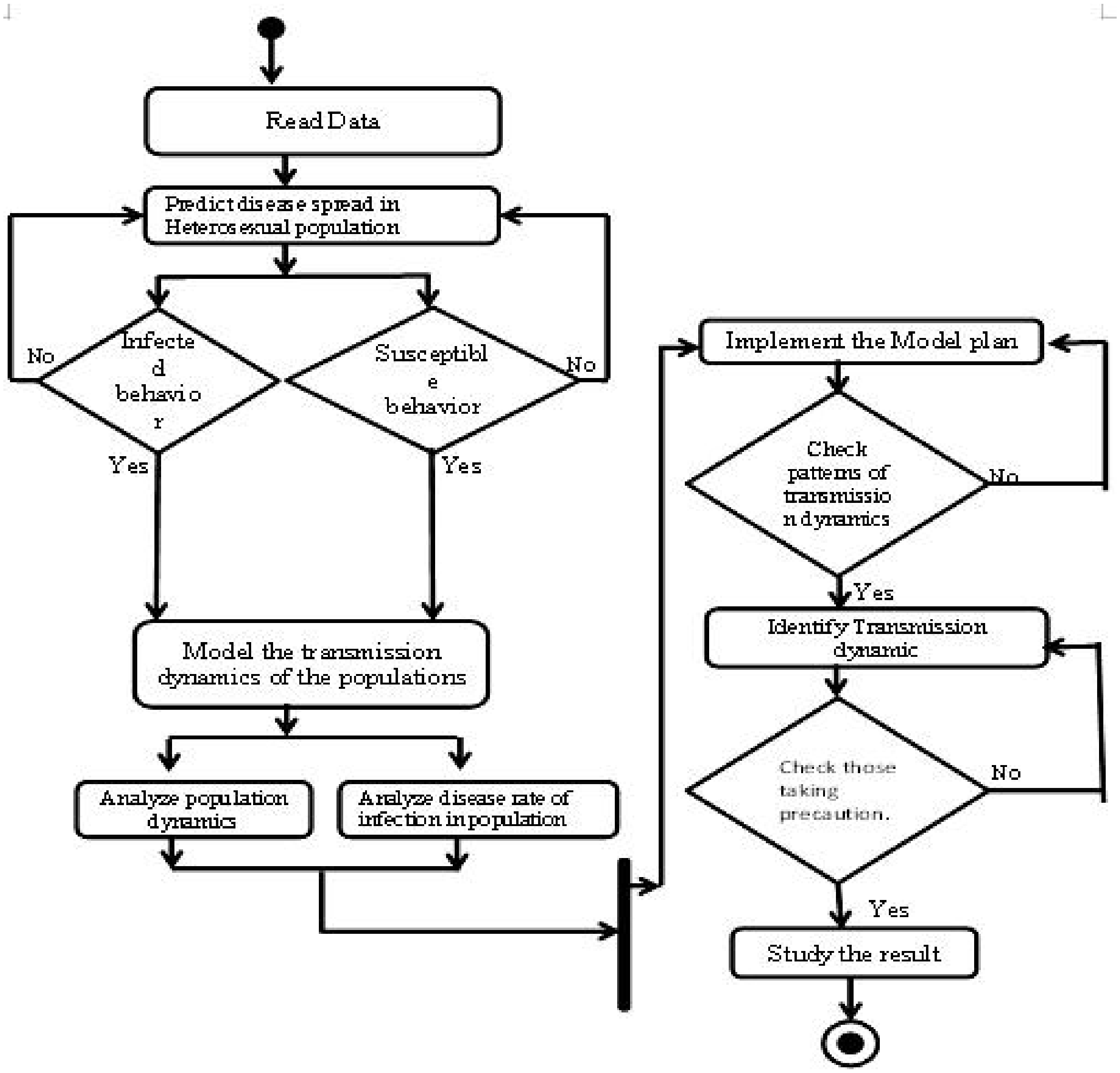

Figure 2: Activity Diagram for the Algorithm

Data Collection

i. ***Primary data:*** The primary data source for this research was laboratory and non-governmental organization health workers. The (Mubi) satellite databanks provided useful information about sexually transmitted diseases.

ii. ***Secondary data:*** Books, journals, electronic resources, and other relevant initiatives are the sources of the secondary data for this study. Specifically, Ishaku et al. (2020), Global Aids Monitoring (2020), Ghassabi et al. (2018), and Gumel (2010) provided the information.

Method of Data Analysis

The research objectives were achieved through the following steps: problem definition, formulation of mathematical equations, algorithm design, computational framework using UML diagrams, implementation in MATLAB, and interpretation of the simulated results using the extracted datasets.

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Model Equations

$$\frac{dS_u}{dt} = k_1 N - (k_2 + k_3) S_u \quad (2)$$

$$\frac{dH_u}{dt} = k_3 S - (k_4 + k_5) H_u \quad (3)$$

$$\frac{dH_a}{dt} = k_5 H_u - (k_6 + k_7) H_a \quad (4)$$

$$\frac{dH_s}{dt} = k_7 H_a - (k_8 + k_9) H_s \quad (5)$$

$$\frac{dH_b}{dt} = k_9 H_s - (k_{10} + k_{11}) H_b \quad (6)$$

$$\frac{dH_x}{dt} = k_{11} H_b - (k_{12}) H_x \quad (7)$$

Numerical Experiments

Below is the numerical scheme for solving the model equations (1-7) as follows:

$$N = 41011622 + 1212610 + 212261 + 1480 + 640 + 530 \quad (8)$$

$$\frac{dS}{dt} = 0.68N - 0.52S \quad (9)$$

$$\frac{dH_u}{dt} = 0.32S - 0.87H_u \quad (10)$$

$$\frac{dH_a}{dt} = 0.60H_u - 1.1H_a \quad (11)$$

$$\frac{dH_s}{dt} = 0.53H_a - 1.1H_s \quad (12)$$

$$\frac{dH_b}{dt} = 0.60H_s - 0.52H_b \quad (13)$$

$$\frac{dH_x}{dt} = 0.32H_b - 0.15H_x \quad (14)$$

RESULTS AND DISCUSSION

In Tables 1 and 2, parameters and values were used to generate the results.

Table 2: Parameter Description and Values

Parameter	Description	Dim.	Value	References
K_1	Birth rate of S	10^5	0.68	Global Aids Monitoring, 2020
K_2	Death rate of $S10^6$	0.20	Ghassabi *et al.*, 2018	
K_3	Rate of H_u.	10^6	0.32	Ghassabi *et al.*, 2018
K_4	Death rate H_u	10^7	0.27	Assumed
K_5	Rate of H_a	10^5	0.60	Assumed
K_6	Death rate of H_a	10^5	0.57	Global Aids Monitoring, 2020
K_7	Rate of H_s	10^5	0.53	Ghassabi *et al.*, 2018
K_8	Death of H_s	10^6	0.50	Global Aids Monitoring, 2020
K_9	Rate of H_b	10^5	0.60	Assumed
K_{10}	Death rate of H_b	10^5	0.20	Assumed
K_{11}	Rate of H_x	10^5	0.32	Assumed
K_{12}	Death rate of H_x	10^6	0.15	Assumed

Equations (8) to (14) were used

In the Susceptible Individuals, the downward path persists until around year 50, when the S group reaches its lowest point. The declining trend covers potential advancements in educational opportunities and the implementation of awareness programs (Bhunu *et al.*, 2011).

The Patterns in HIV-Infected Unaware Individuals S_u not only highlight the challenges and vulnerabilities during the early years but also stress the positive impact of sustained efforts in the realms of public health, education, and healthcare infrastructure, resulting in a commendable reduction in the population of HIV-infected individuals unaware of their status over the extended temporal horizon covered by the dataset.

The HIV Infected Aware Individuals H_a patterns not only underscore the successes achieved in the realms of healthcare and education but also reflect a collective global commitment to curbing the prevalence of HIV and enhancing the overall well-being of affected individuals. This serves as evidence of the value of combined efforts on a global scale in the fight against HIV, as evidenced by the sustained reduction in the population of HIV-infected individuals who are aware of their status. An effective public health education campaign toward changing risky behavior requires a combined effort from all the stakeholders (Hussaini *et al.*, 2011).

The HIV with Syphilis Infected Unaware Individuals H_s dataset highlights the importance of continuous monitoring, targeted awareness campaigns, and effective public health strategies to address the co-infection of syphilis in individuals living with HIV. The observed trends provide invaluable insights for policymakers and healthcare professionals, facilitating the design of targeted interventions to enhance overall health outcomes in this specific population.

The Simulation of HIV with Syphilis Infected Individuals shows the dynamic nature of healthcare practices in addressing co-infections among the HIV-positive population (Oluwaseun *et al.*, 2008). The observed patterns highlight the importance of continuous monitoring, adaptive strategies, and the need for reactive healthcare systems to address the evolving landscape of co-infections.

HIV with Syphilis Infected Aware Individuals on treatment H_x dataset points towards a commendable pattern of increasing awareness, active seeking of treatment, and sustained adherence. These observations help in managing co-infections among HIV-positive individuals.

In the Simulation of the Total Population of individuals N, the dataset serves as a valuable record of the changing total population over the specified period. The gradual decline, marked by occasional fluctuations, underscores the need for comprehensive analysis and additional contextual information to unravel the specific factors influencing the observed population trends.

CONCLUSION

A computational model for HIV with syphilis infection in women characterized by poverty, gender, and relationship dynamics was carried out. The model shows that good education campaigns, advancements in public health interventions, awareness campaigns on STD dynamics, confidential counseling/ testing, and general improvements in testing and treatment facilities for STDs are considered the best intervention strategies for controlling HIV with syphilis among women. The experiment has shown that the model for the transmission dynamics of HIV with syphilis (HIV with syphilis) is effective.

Recommendations

Due to the current spread of STDs among young women, prevention is the key. The researcher put forward the following recommendations:

i. All pregnant women need to be tested and treated if infected with STDs, during the antenatal period.

ii. For unmarried individuals, it will be good to get tested, along with a partner, before having sex.

iii. For discordant couples, Pre-exposure prophylaxis (PEP) medication is encouraged, especially for HIV, to reduce their risk of contraction.

iv. There is a need to engage in discussion with a partner about sexual history before sex.

v. It is important to know what type of STDs to test for, as well as the latency period of any STDs one might have been exposed.

vi. Finally, future work on HIV and gonoriahe should be considered to take care of the STDs that has eaten deep into the young generation of young adult.

REFERENCES

Abiodun G. J. (2012). Mathematical modeling and analysis of HIV/AIDS control measures, Masters of Science Thesis, Department of Mathematics and Applied Mathematics University of the Western Cape.

Asekun-Olarinmoye, E.O., Olajide, F.O. & Asekun-Olarinmoye, I.O (2011). HIV/AIDS preventive measures among In-School Adolscents in a sub-Urban Community in Southwestern Nigeria, *Journal of Life and Physical Sciences,* 4(1), 81-96,

Bhunu, C. P., · Mushayabasa, · S., Kojouharov H., · & Tchuenche, J. M. (2011). Mathematical Analysis of an HIV/AIDS Model: Impact of Educational Programs and Abstinence in Sub-Saharan Africa, *Journal of Mathematical Modelling and Algorithms* available at DOI 10.1007/s10852-010-9134-0

Centers for Disease Control and Prevention (2020). About HPV. Retrieved from https://www.cdc.gov/hpv/parents/about-hpv.html

Garba, S.M., & Gumel, A.B.*(2010).* Mathematical Recipe for HIV Elimination in Nigeria, *Journal of the Nigerian Mathematical Society*, 29 (1), 51-112, 2010

Ghassabi, F., Malekzadegan, Y., Ebrahim-Saraie H.S., Heidari, H. Sabet, M.Abdollatif Bagheri, A.,…Motamedifar, M. (2018). Frequency of gonorrhea and syphilis co-infection and related risk factors in HIV Patients from Shiraz, South of Iran. *Caspian Journal of International Medicine*, 9(4), 397-402.

Global AIDS Monitoring (2020). Country progress report-Nigeria

HealthLine (2021). "HIV Diagnosis and Symptoms", Available in http://healthline.com.

Hussaini, N., Winter, M., & Gumel, A.B.(2011).Qualitative assessment of the role of Public Health Education program on HIV transmission dynamics, *Mathematical Medicine and Biology*. Available at https://www.researchgate.net/publication/44617437

Ishaku, A., Gazali1, A. M., Abdullahi1, S. A., & Hussaini, N. (2020). Mathematical Biology Analysis and optimal control of an HIV model based on CD4 count, *Journal of Mathematical Biology*, © Springer-Verlag GmbH Germany, part of Springer Nature 2020 https://doi.org/10.1007/s00285-020-01508-8

Kimberly, A. W., & Gail, A. B. (2015). Sexually Transmitted Diseases Treatment Guidelines, National Center for HIV/AIDS, Viral Hepatitis, STD, and TB Prevention Emory University, *Atlanta, Georgia*, *64(3), 1-140*

Mark, C. R.N. (2020). How STDs Facilitate HIV Infection and Vice Versa, Medically Reviewed by Latesha Elopre, MD, MSPH

Nigeria Galleria, (2021). HIV/AIDS: Treatment, Diagnosis and Prevention. Available in https://www.nigeriagalleria.com/Community-Health/HIV.html

Oladotun, M. O., & Suares C. O. N.(2016). Mathematical Model for an Effective Management of HIV Infection, *International Journal of BioMed Research*, 3(1), 6 , available at http://dx.doi.org/10.1155/2016/4217548

Oluwaseun, S., Chandra, N. P., & Abba, B. G. (2008). Mathematical Analysis of the Transmission Dynamics of HIV/TB Co-infection In The Presence of Treatment, *Mathematical Biosciences and Engineering Journal*. 5(1), 94-112, Retrieved from http://www.mbejournal.org/

Omondi, E.O., Mbogo, R.W., & Luboobi, L.S. (2019). A mathematical modeling study of HIV infection in two heterosexual age groups in Kenya, *Journal of Infectious Disease Modeling* 4 (1) 83-98,

The well Project (2021). Sexually Transmitted Diseases, One woman at a time, also available at www.thewellproject.org

World Health Organization [WHO](2021). Facts Sheet on HIV/AIDS, Retrieved from https://www.who.int/news-room/fact-sheets/detail/hiv-aids