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COMPUTATIONAL MODELING FOR EARLY STAGE SYPHILIS INFECTION

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ABSTRACT
Computational modeling refers to the use of computer programs to simulate and study the behavior of systems using an algorithmic approach. Sexual Transmitted Diseases (STD) contributes major in the death of young adults in Nigeria, about 2.1% occur every year. The number seems to be growing rapidly for various reasons, such as negligence towards sex practices and life style. In this paper, computational modeling on the transmission dynamics and control of early stage of syphilis infection was built while incorporating sex education, voluntary counseling and treatment. The method adapted first we designed, developed, formulate a mathematical equations for the compartment. Equations were converted into an algorithm and subsequent simulation in MATLAB ODE 45, 2023.. We found that changes have different impacts depending on the factors promoting the transmission dynamics. The parameter used were presented on a graph size using the control measures, $k = 0.9$, $\beta = 0.9$, $\sigma_1 = 0.50$, $\sigma_1 = 0.9$, $\Psi = 0.9$, $\varepsilon_1 = 0.9$, $\varepsilon_2 = 0.9$, $\xi = 0.9$, $\tau_1 = 0.7$, $\tau_2 = 0.75$, *and* $\tau_3 = 0.75$ *which confirmed the accuracy and reliability of the developed model. The study shows a commendable pattern of increasing awareness, active treatment, and sustainable counseling towards guiding future initiatives. Different methods and materials are urgently needed to educate the population about early detection of Syphilis. These may include posters with typical diagram, television, and other scenarios of communication. Syphilis remains preventable if individuals can work on their high-risk sexual behaviours. The developed model has pave way for valuable insights into informed decisions concerning health related sexual problem. There is urgent need to take good preventive measures especially among sex age groups.*

Key words: Computational, modeling, syphilis, Infection, Prevention

INTRODUCTION
According to Pat (2022), computational model refers to the use of computer programs to simulate and study the behavior of complex systems using an algorithmic approach. Modeling representation often takes the form of an abstract formal description, such as a system of equations or a set of logical formulae. One application of computer modeling is to simulated scenarios where computers provide a low-cost and safe way to create events with minimal loss of meaning as demonstrated in Figure 1. for a simple computational modeling environment.

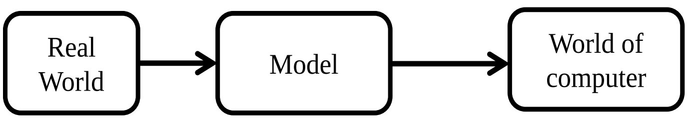

Figure 1 Computational Modeling Environments (Pat, 2022)

Computational modeling has shown to be an extremely effective tool for analyses that forecast occurrences like population shifts. Similarly, both basic and complicated computer models may need measuring input variables and the correlations among them in order to provide numerical output that can be used to forecast certain real-world conditions. Nevertheless, modeling is still widely used because it is frequently the only way to address significant scientific topics. The model can be used to forecast likely results under known circumstances.

STDs have increased challenges affecting communities globally over the past two decades. Productive family members are lost due to the disease, leaving children and other dependents without means of support. Economically STDs have caused havoc within the country/communities due to the high costs involved in managing the affected and infected people. Considerable gaps remain in the quantity and quality of information available in Nigeria on STDs to help understand the underlying dynamics of the diseases and their likely future course (Bulus *et al*. 2024).

Research by Mark (2020) indicates that STDs like as syphilis and gonorrhoea facilitate HIV's entry into susceptible cells and tissues, whereas co-infection with STDs enhances the infectivity of individuals with HIV, hence increasing the likelihood of viral transmission to others.

Several 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 STDs prevalence, even in the presence of a vaccine and/or treatment (Ishaku *et al*. 2020). Some studies tend to emphasize the use of pharmaceutical interventions such as vaccines, which are not readily available for example in resource-poor nations like Nigeria.

The aim of this paper is to build computational models for early stage syphilis infection, while incorporating sex education, voluntary counseling and treatment. Thus, the specific objectives are to:

i. Designed a computational model for the transmission dynamic of Syphilis infection.
ii. Developed a computational model that simulates the transmission dynamic of Syphilis infection in various populations.
iii. Evaluate the effectiveness of existing STD control strategies using the developed model

REVIEW OF RELATED WORKS

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

One study showed that 85% of HIV-infected patients with ocular syphilis had concomitant neurosyphilis. Once syphilis is diagnosed, clinicians must consider the possibility of neurosyphilis and decide whether a lumbar puncture (LP) is indicated. In HIV-infected patients, neurosyphilis can occur at any stage of the disease, and often causes typical symptoms or none at all. Experts agree that LP is necessary for HIV-infected patients with syphilis who present with neurologic symptoms, but the question of how to manage HIV-infected patients with asymptomatic syphilis has not been settled. The CDC guidelines recommend LP for three groups of asymptomatic HIV-infected patients: those who present with late latent syphilis, those with syphilis of unknown duration, and those who do not demonstrate appropriate serologic response after syphilis treatment (CDC, 2024).

Theparod, (2015) proposed and studied a network modeling of STDs, while applying mathematical models for the analysis of sexually transmitted disease epidemics using a closed heterosexual population contacts. Their model is formulated based on ABC strategies which also look alike to the new model. They consider medication as the control strategy which is not readily obtainable in resource poor country like Nigeria that depends mostly on foreign aids when it comes to the matter of STDs.

Kretzschmar and Heijne (2017) studied a pair formation models for sexually transmitted infections and conclude that transmission of STIs are successful in mono marriage and forgot that transmission and spread is faster in polygamous marriages. According to them infection may be conditionally occurring. This may cause serious problem on the partner if prolong on the long way due to various effects. For example if partnership duration is also small, and gaps between partners are extended, transmission dynamics may take place. Our work looks alike in terms of intervention strategies.

The Syphilis and its Stages

Godson (2024) stated, syphilis is one of the deadly sexually transmitted diseases. The analytical and numerical solutions from their study demonstrate that there is a decline in the number of infected individuals with the increase in the values of the treatment rates. They further suggest that the effective control strategy of syphilis and concurrent application of higher treatment rates for early stages of syphilis infections is helpful.

The bacterium syphilis called *Treponema pallidum* is in stages. It initiate with primary syphilis that is clinically happen in some days or weeks of infection. It shows signed and symptoms at the genital sore(s) or lesion(s), usually at the bodily site. The second stage of syphilis is noticed at the skin side with rashes and slippery membrane lesions (sores) or both at a site(s) distant from the primary lesion (CDC fact sheet, 2020). Following a latency period, which may last for decades without obvious signs or symptoms, the condition may evolve to tertiary syphilis, the most severe stage of the illness, due to insufficient diagnosis, treatment, and/or timely care. Tertiary syphilis is uncommon but can impact various organ systems, including the brain, nerves, eyes, heart, blood vessels, liver, bones, and joints (CDC fact sheet, 2020).

Nonetheless, ocular and neurologic syphilis may manifest at any phase of the disease. Congenital syphilis transpires when a pregnant mother transmits the infection to her foetus during gestation. While recovery from a syphilis infection is possible, untreated syphilis might elevate the chance of acquiring HIV. Congenital syphilis may result in premature birth, stillbirth, and neonatal mortality. Symptoms of syphilis may encompass rash, tiredness, fever, headaches, arthralgia, weight reduction, and alopecia. If ignored, late-stage syphilis may result in vision impairment, hearing loss, memory decline, psychiatric disorders, infections of the brain or spinal cord, cardiovascular disease, and mortality (Wang *et al*. 2023).

MATERIALS AND METHOD

Both primary and secondary data were used in the paper. Some literatures were used in getting data are reports of National Population Commission (2023), Centre for Diseases Control (2023) was extracted for initial input for the computing among others as shown in Table I. Adapted theoretical data from Ishaku *et al*., (2020) and AHNI, (2023) was used for the variables and parameters in the model. Other literatures were used and other values were assumed.

To achieve the objectives of the paper, the problem was define, formulation of mathematical equations, the second stage is the conversion of the equations into algorithm, the third stage is designing a computational framework using UML diagrams, the fourth stage was simulation in MATLAB for interpretation of the results to determine the efficiency of the model, and finally used Python 3.12.0 (2023) with Visual Studio compare the results on a graph size. At this point, we examined the behavior of the model equations obtained. All the compartments and population are examined.

Model Assumption for early Syphilis infection

Individuals are characterized by disease status based on the following assumptions:

i. The age limit is ignored , the population is represented by *N,*
ii. The interaction between the susceptible and the infected is assumed to be interactive.
iii. Transmission is considered by contact only,
iv. The susceptible and infected use preventive measures
v. population are recruited into the susceptible compartment at an endless rate
vi. Death rates are the same for all the compartment;
vii. Infected persons can die naturally because of Syphilis Infection;
viii. Individuals infected with syphilis can recovered, although they can contact the disease.
ix. We consider the early (Primary) stage of syphilis
x. The preventive measures used are sex education campaign, voluntary counselling and Treatment of other kinds of STD.
xi. All the parameters stated above are constant.

Table I: Description of the Model Variables for early Syphilis infection

Variables	Deception
$S_u(t)$	Uneducated susceptible individuals,
$S_e(t)$	Educated susceptible individuals,
I_u^s (t)	Syphilis infected individuals unaware
I_e^s (t)	Syphilis infected individuals educated
I_t^s (t)	Syphilis infected individuals on treatment
R^s	Recovered individuals from syphilis infection

Table II: Description of Parameters of the Model for early Syphilis infection

Parameter	Description
Λ	Recruitment rate into the susceptible educated and uneducated individuals
p	Proportion of Newly enrolled persons that are enlighten
λ_h	Rate at which, S_u, infectious rate λ_h enter I_u^s,
λ_s^u	Rate at which susceptible individuals unaware infected with syphilis, I_u^s
λ_s^e	Rate at which susceptible individuals unaware infected with syphilis, I_u^s
$(1-k)\,\lambda_s^e$	Reduced Rate of S_e acquire the syphilis , k ∈ (0, 1] and move to I_e^s.
σ_1	Rate of infected syphilis individuals unaware become aware and start treatment
σ_2	Rate of infected syphilis individuals aware become aware and start treatment
ϕ_1	Rate of infected syphilis individuals on treatment recovered
ω	Recovery rate from syphilis with chances of infected again with the disease.
ΨI_u^s	Rate of infected individuals with syphilis acquired knowledge about the disease
Ω	Regulating parameter of I_s^e to I_u^s
$(1-k)\,\lambda_h$	Reduced Rate of S_e acquire the infection, k ∈ (0, 1] and move to H_u.
ξ	Rate S_u could be educated and move to S_e.
μ	Natural death for all classes of individuals

In the model, it is also assumed that sexually active individuals are recruited into the susceptible population at a constant rate Λ. The fraction p of the newly recruited individuals that are educated enter S_e and the remaining (1− p) individuals enter, S_u. We also use β as the effective contact rate for the force of infection, thus;

$$\lambda_s^e = \beta\left(\frac{I_e^S + \Omega\ \ I_u^S}{N}\right) \qquad (1)$$

The schematic diagram in Figure 2 describes the movement of individuals from one class to another in the model. The total population *N(t)*, at time *t*, is subdivided into six compartments. Educated individuals (S_e) at this point are those individuals who are educated towards sexual behaviour and its associated risks. Uneducated individuals are those who do not receive the knowledge and danger of STDs. Therefore,

$N(t) = Su(t) + Se(t) + I_u^s\ (t) + I_e^s\ (t) + I_t^s\ (t) + R^s$ (2)

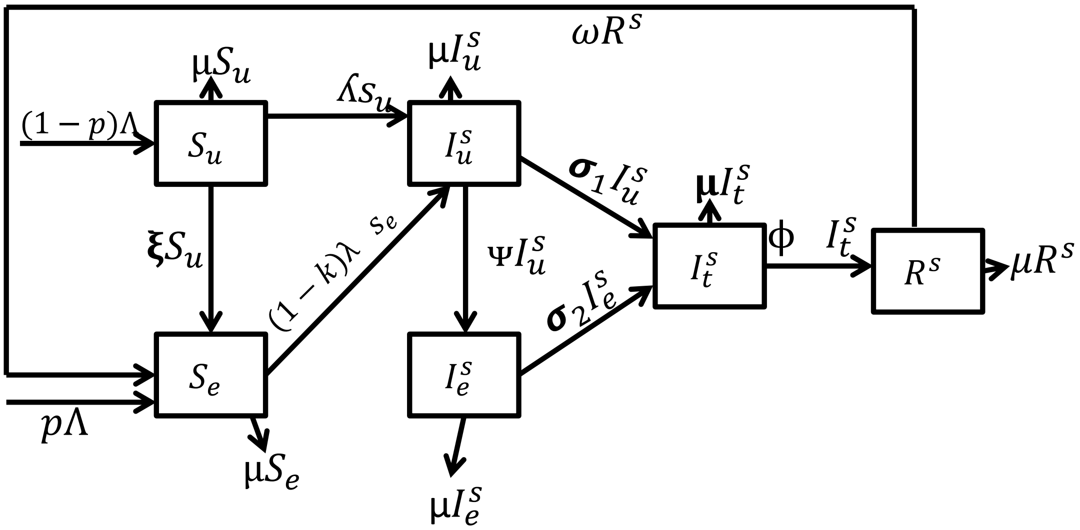

Figure 2: Model diagram of the transmission dynamics of early Syphilis Infection

The Model Equations for Syphilis infection

From the diagram in Figure 2, the following system of non–linear first order ordinary differential equations;

$$\frac{ds_u}{dt} = (1-p)\Lambda - (\xi + \lambda \quad + \mu)s_u \quad (3)$$
$$\frac{ds_e}{dt} = \left(P\Lambda \quad + \omega * R^s + \xi * S_u - [(1-k)\lambda \quad + \mu)\right)s_e] \quad (4)$$
$$\frac{dI_u^s}{dt} = ʎS_u - (1-k)ʎS_e - [(\varphi + \sigma_1 + \mu)I_u^s] \quad (5)$$
$$\frac{dI_e^s}{dt} = \varphi I_u^s - [(\mu + \sigma_2)I_e^s] \quad (6)$$
$$\frac{dI_t^s}{dt} = \sigma_1 I_u^s - \sigma_2 I_e^s(\mu + \phi \quad)I_t^s \quad (7)$$
$$\frac{dR^s}{dt} = \emptyset \quad I_t^s - (\omega + \mu)R^s \quad (8)$$

With the initial conditions

*(Su(*0*)* ≥ 0*, Se(*0*)* ≥ 0*,* I_u^s *(*0*)* ≥ 0, I_e^s*(*0*)* ≥ 0, I_t^s *(*0*)* ≥ 0, R^s *(*0*)* ≥ 0, ∈ R8 + − {0*,* 0*, . . . ,* 0}, where $\lambda_s^{,e}$ are given in Eq. (1).

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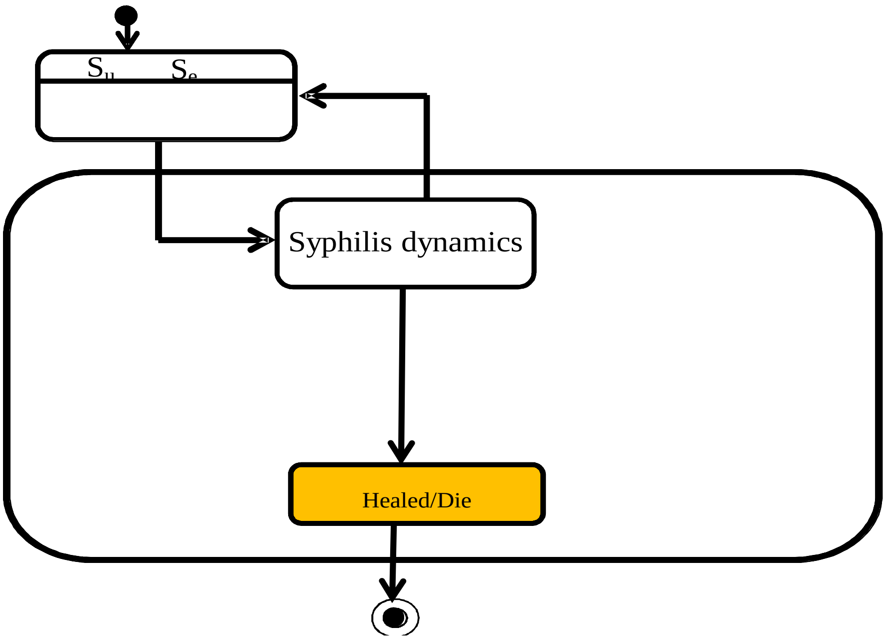
Representation of The Modified Model using State Diagram for early stage Syphilis Infection



Change in the susceptible uneducated (S_u) at a time (t) is the recruitment rate (inflow) minus the number of deaths, rate of acquiring health education, and the rate at which the infected uneducated individuals are recruited into with syphilis yet unaware.

$$\frac{ds_u}{dt} = (1-p)\Lambda - (\xi + \mu + \Lambda)s_u \qquad (9)$$

These was also run for equations (4) to (8)

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

Program Algorithm

Change in the susceptible uneducated (S_u) at time (t)

Step 1: Read P, Λ, ξ, μ,, λ , $S_u$where parameters are obtained from Tables 1 & 2

Step 2: Read [t, y] , t = [0, 100], Y_1=Y_0

Step 3: Evaluate $[(1-p)\Lambda - (\xi + \mu + \Lambda)s_u]$

Step 4: [out = [, ds_u/dt], where y1 stand for Susceptible uneducated individuals

Step 5: Determine the transmission dynamics of S_u

Step 6: Inform time and go to step 3

The algorithm was also run for all equations (2) to (8)

Numerical Experiments

Table1: Parameter description, values and reference used

Parameter	Decryption	Dimension	Value	Reference
Λ	Recruitment rate	year−1	2,359,067	NPC(2024)
P	Proportion of Newly recruited Individuals that are educated	year−1	0.5	Ishaku *et al.* (2020)
k	Efficacy of edu. campaign in	Dimensionless	0.7	Ishaku *et al.* (2020)

	preventing infection			
β	Effective contact rate	$year^{-1}$	0.45	Hussaini *et al* (2011)
α	Progression rate to H_{as}	$year^{-1}$	0.05	Assumed
ω	Recovering rate of R	$year^{-1}$	0.431	Godson *(2022)*
$\boldsymbol{\sigma}_1$	Treatment Rate of syphilis unaware	year-1	0.21	Assumed
$\boldsymbol{\sigma}_2$	Treatment Rate of syphilis educated	year-1	0.45	Assumed
Ψ	rate acquired knowledge on syphilis	year-1	0.61	Assumed
ϕ	Recovery Rate of I_t^s	year-1	0.67	Godson (2022)
$\boldsymbol{\xi}$	Rate of edu *campaign*	$year^{-1}$	0.1	Ishaku *et al (2020)*
μ	Natural death rate	$year^{-1}$	0.019	Hussaini *et al* 2011

Table 2:Variable description and initial values from Godson (2022), Ishaku *et al*. (2020) & AHNI(2024)

Variable	Description	Initial
S_u	Uneducated susceptible individuals	61,517,433
S_e	Educated susceptible individuals,	41,011,622
I_u^s	Syphilis infected individuals unaware	255885
I_e^s	Syphilis infected individuals educated	193825
I_t^s	Syphilis infected individuals on treatment	77530
R^s	Recovered individuals from syphilis infection	3839

Rearranging equations (3-8), we get

$\frac{ds_u}{dt}$ y1(t+1) = (1-p)*Λ-(**ξ**+z1+μ+z3)*y1 (10)

$\frac{ds_e}{dt}$ y2(t+1) =(p*Λ+ω*y6+**ξ***y1-[(1-k)*z1+μ+(1-k)*z3)*y2] (11)

$\frac{dI_u^s}{dt}$ y3(t+1) = z3*y1-[(Ψ+z2+**σ**1+μ)*y3] (12)

$\frac{dI_e^s}{dt}$ y4(t+1) = (1-k)*z3*y2+ Ψ *y3-[(μ+(1-k)*z2+**σ**2)*y4] (13)

$\frac{dI_e^s}{dt}$ y5(t+1) =[**σ**2*y4 +**σ**1*y3-(μ+ϕ1)*y5] (14)

$\frac{dR^s}{dt}$ y6(t+1) = [ϕ1*y5- (ω+μ)*y6] (15)

Equations (10) to (15) was used for the simulation.

RESULTS AND DISCUSSION

This section described the numerical results obtained from the modeling with variable parameters used. This was plotted on a graph size with increase on the control parameters. We used ODE45 solver in MATLAB to carry out the simulations for the modified model. The baseline values for the variables and parameters presented in Table 1 and Table 2 were used. We looked at the control measure on the entire compartment and make decision as applicable.

Figure 4 using parameters and variables in Table 1 and Table 2, under consideration describes the dynamic fluctuations in the population of uneducated susceptible individuals (S_u) across the temporal spectrum, measured in years. An evident flow in the S_u group is visible during the initial years, closing in a zenith at the end of year 35. Following the increase in S_u numbers, apparent and persistent descent commences around same year 35, exhibiting a gradual reduction in S_u prevalence. This downward trajectory persists until around year 100 when the S_u group reaches its lowest point at 9,354,123 individuals from 61,517,433. Possibility for this declining trend covers potential advancements in health/sex educational opportunities, voluntary counseling and treatment among the population, this agreed with Bhunu, *et al.* (2011) on susceptible uneducated individuals.

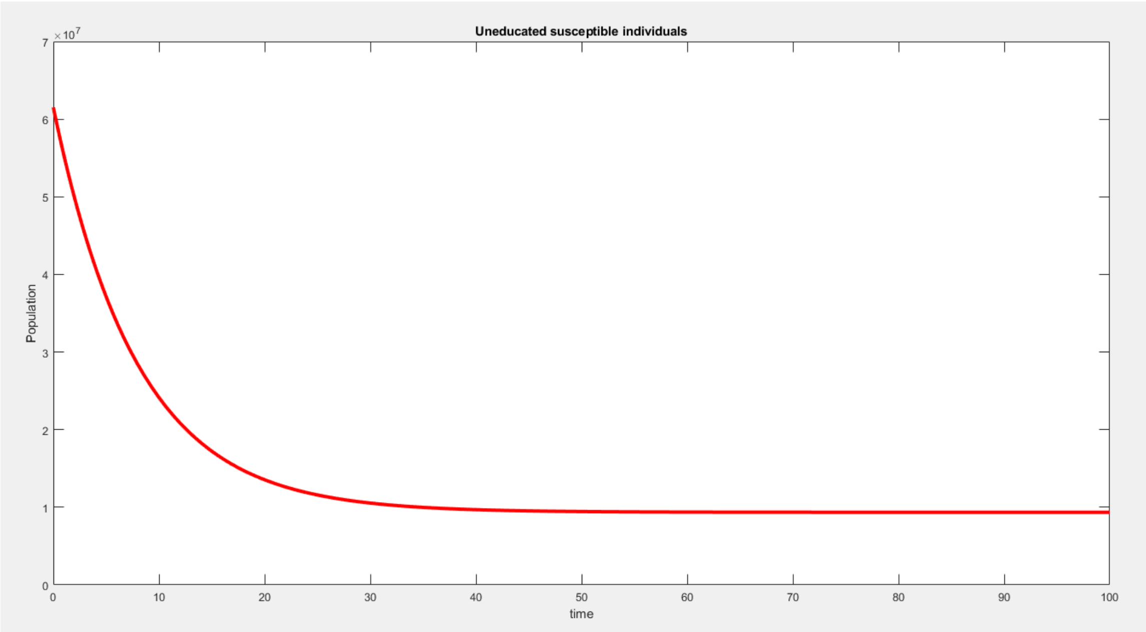


Figure 5: Simulation for Uneducated Susceptible Individuals

Here the favourable interplay of VTC and treatment that yield positive results after 50 years valued 35804. The drastic change point improvement in VTC combined efforts all stakeholders in syphilis management. Recovery is possible but management should also be adhered to in regard to syphilis infection. The earlier the understanding syphilis dynamics over time the better the recovery although syphilis has no immunity it can be contracted again. This means intervention by counselors needs to be improved.

Discussion of Results

According to research by Mark (2020), STDs like syphilis not only provide HIV easier access to vulnerable cells and tissues of the body, but co-infection increases the infectivity of the person with HIV-making them more likely to transmit the virus to others. Syphilis as a bacterium is a causal factor to HIV acquisition.

Syphilis in particular appears to be dangerous although it is curable. This work demonstrated increase in application of higher control measures, k = 0.9, $\beta = 0.9$, $\sigma_1 = 0.50$, $\sigma_1 = 0.9$, $\Psi = 0.9$, $\varepsilon_1 = 0.9$, $\varepsilon_2 = 0.9$, $\xi = 0.9$, $\tau_1 = 0.7$, $\tau_2 = 0.75$, and $\tau_3 = 0.75$ was effective in reducing the transmission rate as suggested by Godson (2024).

The study also demonstrated how people are ignorant of STDs danger, especially young adults who normally play around with issue of sex. Although Syphilis infection can be recovered possibly at early stage, but if syphilis is co-infected with HIV, the chance of recovery is narrow. This also shows that individuals are encourages at all level to practiced safer sex especially in all age group. This means intervention by counselors needs to be improved especially towards adherence to treatment regimens and its management.

CONCLUSION

At present, there is no widely accepted model for controlling some STDs like early stage of syphilis. In Nigeria, due to the perception of the general public about STDs, together with the religious and cultural beliefs of most Nigerians (death is divine), there was little behavioral change in matters of sex and sexual practices among people. Therefore, the STDs spread silently (unnoticed) through the sexual networks in all social classes. Thereby gives birth to the following problems: Low level of sex education, limited awareness campaigns on STDs, insufficient testing facilities, and treatment during the early years. The result of the study has demonstrated that, there was no standard policy placed by government to checkmating early stage Syphilis Infection or strict adherence to treatment and good management practices for Syphilis Infection.

RECOMMENDATIONS

A computational modeling for early stage Syphilis infection was carried out. Find below some recommendations:

i. Government should put more effort towards educating the people especially by putting an acceptable policy that will be implemented nation-wide to serve as a better strategy in controlling spread of syphilis.
ii. Government should provide good confidential STD testing and Treatment centres at all levels.
iii. There is a need to encourage research works and its availability on models of sexually transmitted diseases.

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