ANALYSIS OF TRANSMISSION DYNAMICS AND CONTROL OF STRONGYLOIDES STERCORALIS USING MATHEMATICAL MODELING IN PANKSHIN LOCAL GOVERNMENT AREA OF PLATEAU STATE, NIGERIA

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ABSTRACT: *Strongyloides stercoralis infection is common among children living in rural areas in developing countries especially in sub-Saharan Africa with serious public health significance. This study presents a mathematical modeling and analysis of transmission dynamics and control of Strongyloides stercoralis in Pankshin Local Government Area of Plateau State, Nigeria. A mathematical model based on the Susceptible-Exposed-Infected-Treated-Public Health Education-Filariform Larvae (SEITPF) compartments for Strongyloides stercoralis was formulated. A qualitative analysis was performed and disease equilibrium points together with their stabilities were derived. The basic reproduction number, R_0, was computed and used as a threshold value using the next generation matrix method. It was established that the unique endemic equilibrium point is locally asymptotically stable provided $R_0 > 1$. Additionally, to ascertain the impact of various parameter values on the growth of Strongyloides stercoralis, a sensitivity analysis of R_0 was conducted. Ultimately, a numerical analysis of these parameters' effects on the infected humans revealed that treatment, public health education, and good personal hygiene should all be used in tandem to effectively eradicate Strongyloides stercoralis and other NTDs infections in the study area.*

KEYWORDS: *Strongyloides stercoralis,* mathematical modeling, transmission dynamics, control.

INTRODUCTION

Strongyloides stercoralis is the most common cause of maternal and childhood illnesses in developing tropical and subtropical countries (Ali *et al*., 2023). It is a soil-transmitted helminth infection caused primarily by the nematode parasites called *Ancylostoma duodenale* and *Necator americanus*. The latter is the predominant etiologic agent for *Strongyloides stercoralis* infection (Bala & Yakubu, 2010). *Strongyloides stercoralis* is one of the neglected tropical diseases listed by WHO (Ombugadu *et al.*, 2022). Neglected tropical diseases resulted in 46–57 million disability-adjusted life years lost and they account for the 4th leading cause of communicable diseases (Berhanu, 2018). 3,000–6,500 persons lose their lives to *Strongyloides stercoralis* every year. *Strongyloides stercoralis* compromises an individual's immune system and raises the possibility of contracting diseases like HIV/AIDS, convulsions, portal hypertension, and diarrhea (Edema *et al.*, 2021). In sub-Saharan Africa, *Strongyloides stercoralis* infection is the most common cause of anemia. *A. duodenale* consumes approximately 150 mL of blood daily, whereas *N. americanus* only consumes 30 mL. *Strongyloides stercoralis* can have a long-lasting effect on children's cognitive development and performance; it can reduce academic achievement in schools by 20% (Eniola *et al.*, 2019). In sub-Saharan Africa, more than 200 million people have been infected with hookworm and 90 million of them were children. In Ethiopia, more than 11 million people were infected with *Strongyloides stercoralis*, the third highest burden in sub-Saharan Africa (Peter & Kamath, 2019). *Strongyloides stercoralis* infection is endemic and highly prevalent among Nigerians living between latitudes 350 N and 300 S where the disposal of faeces is inadequate or where the environmental conditions such as humidity and temperature favour the development of the infective worm larvae (WHO, 2015).

Strongyloides stercoralis transmission occurs when third-stage infective filariform larvae come into contact with the skin. *Strongyloides stercoralis* larvae have the ability to actively penetrate the cutaneous tissues, most often those of the hands, feet, arms and legs due to exposure and usually through hair follicles or abraded skin. Following skin penetration, the larvae enter subcutaneous venules and lymphatics to gain access to the host’s afferent circulation. Ultimately, they enter the pulmonary capillaries where they penetrate into the alveolar spaces, ascend the brachial tree to the trachea, traverse the epiglottis into the pharynx and are swallowed into the gastrointestinal tract. Larvae undergo two molts in the lumen of the intestine before developing into egg-laying adults approximately five to nine weeks after skin penetration.

One of the main risk factors for *Strongyloides stercoralis* infection is living in or travelling to areas with poor sanitation and hygiene (Pam *et al.*, 2021) These worms are transmitted through contact with contaminated soil or faeces, and people living in areas without access to clean water or proper sanitation are at a higher risk of infection. Research conducted by Eniola *et al.* (2019) among school children in Lafia, Nasarawa State revealed that factors such as the absence of regular wearing of shoes and the absence of proper latrine utilization were significantly associated with *Strongyloides stercoralis* infection. Another risk factor is poverty, as people living in poverty are more likely to live in areas with poor sanitation and may also have limited access to healthcare. Findings from a study by Muslim *et al.* (2019) indicated that low socioeconomic status was highly associated with Soil-Transmitted Helminth infections. Another study by Misikir *et al.* (2017) also indicated that poverty was associated with *Strongyloides stercoralis* infection. Other potential risk factors include walking barefoot,

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working in jobs that involve contact with soil, and having a weakened immune system (Zeleke *et al.*, 2021).

Over the years, mathematical models have aided public health officials and policymakers in making decisions about important intervention initiatives. They can also be used as guiding tools for studying the transmission and control of diseases. It has been thought to play a very useful function in the study and comprehension of the dynamics of transmission as well as the efficacy of the various control techniques of numerous infectious diseases. The World Health Organization lists *Strongyloides stercoralis* as one of the deadliest neglected tropical diseases. The disease is still widespread in many tropical and subtropical countries, especially in the impoverished African nations, despite multiple intervention efforts to stop its spread (Ebrima *et al.,* 2021). Numerous illnesses' regulation and dissemination have been modeled using mathematical techniques (Ebrima *et al.,* 2021). Therefore, the creation of a mathematical model that will aid in the explanation of the spread and management of *Strongyloides stercoralis* is necessary (De Almeida & Moreira, 2007).

MATERIALS AND METHODS

Model Formulation

A deterministic model that describes the transmission dynamics of the Neglected Tropical Diseases (*Strongyloides stercoralis*) was proposed. The work of Ebrima *et al.* (2021) was extended. In their work, the human sub-population was divided into four compartments, i.e., susceptible humans (S_h), exposed humans (S_h), infected humans (I_h) and treatment humans (T_h). We incorporated the public health education on drug treatment which is the compartment (P_h), and also added the compartments for the filariform larvae (F_L) based on the transmission of the diseases.

Basic Model Assumptions

1. All recruitment is carried out in the susceptible class.
2. It is assumed that *Strongyloides stercoralis* transmission occurs when third stage infective filariform larvae come into contact with the skin.
3. Children are more prone and pregnant and lactating women also have an increased risk of anemia from *Strongyloides stercoralis* infections.
4. Contact with the filariform larvae is the only means through which susceptible humans become exposed to the disease.
5. Treated humans can become susceptible again on contact with filariform larvae.

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A Compartmental Chart for the Mathematical Model of *Strongyloides stercoralis*

All recruitment is carried out in the S_h (susceptible compartment) which later moved to the E_h (exposed compartment) where the human population is being exposed with the disease. The infectious class compartment (I_h) is where the human population comes in contact with the filariform larvae (F_L). The filariform larvae is the only means through which susceptible humans become exposed to the disease. Infectious humans are treated which is the class T_h (treatment compartment) through the public health education compartment (P_h).

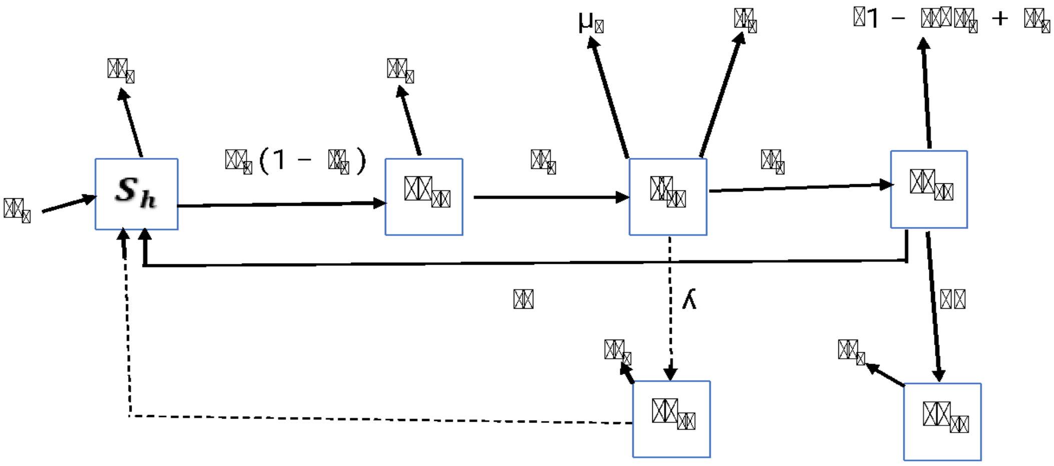

Figure 1: A Compartmental Chart for the Mathematical Model of *Strongyloides stercoralis*

Table 1: Variable Description

Variable	Description
S_h	Susceptible Human
E_h	Exposed Human
I_h	Infected Human
T_h	Treated Human
P_h	Public Health Education Human
F_L	Filariform Larvae

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Table 2: Parameter Description

PARAMETER	DESCRIPTION	VALUE	REFERENCES
α_h	Recruitment rate of human	400	Estimate
μ_h	Natural death rate of human	0.00004379	Chiyak *et al.* (2009)
β_h	Rate of transmission of humans from susceptible to exposed	0.09753	Kalinda *et al.* (2019)
ξ_h	Preventive factor due to WASH	0.1	Ebrima *et al.* (2021)
σ_h	Rate of transmission of human from exposure to infectious	0.0236	Ebrima *et al.* (2021)
Λ	Rate at which human contact the Filariform Larvae	62	Estimate
ρ	Treatment efficacy	0.8	Ebrima *et al.* (2021)
μ_F	Natural death rate of Filariform Larvae	0.2	Assumed
m	Transmission rate of humans from treatment to public health education	0.16	Assumed
γ_h	Transmission rate of humans from infection to treatment	0.3	Woolhouse (1991)
δ_h	Death rate of human due to infection	0.002	Assumed

Model Equation

The model is represented by the following system of ODEs:

$$\frac{dS_h}{dt} = \alpha_h + \rho T_h - (1 - \xi_h)\beta_h S_h - \mu_h S_h$$

$$\frac{dE_h}{dt} = (1 - \xi_h)\beta_h S_h - \sigma_h E_h - \mu_h E_h$$

$$\frac{dI_h}{dt} = \sigma_h E_h - \gamma_h T_h - \delta_h I_h - \mu_h I_h$$

$$\frac{dT_h}{dt} = \gamma_h T_h - \rho I_h - (1 - \rho)\delta_h T_h - \mu_h I_h - mT_h$$

$$\frac{dP_h}{dt} = mT_h - \mu_h P_h$$

$$\frac{dF_L}{dt} = \Lambda I_h - \mu_F F_L$$

With initial conditions $S_h(0) = 40, E_h(0) = 30, I_h(0) = 15, T_h(0) = 10, P_h(0) = 8$ and $F_L(0) = 5$

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Data Analysis

The basic reproduction number R_0 was determined using the next generation matrix and the numerical analysis of the model was conducted using MATLAB.

RESULTS

Mathematical Analysis of the Model

$$\frac{dS_h}{dt} = \propto_h + eT_h - (1-\xi_h)\beta_h F_L S_h - \mu_h \; \frac{dB_h}{dt} = (1-\xi_h)\beta_h F_L S_h - \sigma_h E_h - \mu_h E_h \; \frac{dI_h}{dt} = \sigma_h E_h - \gamma_h T_h - \delta_h I_h - \mu_h I_h \; \frac{dT_n}{dt} = \gamma_h T_h - (1-\rho)\delta_h T_h - \mu_h I_h - mI_h \; \frac{dP_h}{dt} = mT_h - \mu_h P_h \; \frac{dF_L}{dt} = \lambda I_h - \mu_F F_L \} \quad (1)$$

Let $k_1 = 1 - \xi_h$

$k_2 = 1 - \rho$

So that

$$\frac{dS_h}{dt} = \propto_h + \rho T_h - k_1\beta_h F_L S_h - \mu_h S_h \; \frac{dR_h}{dt} = k_1\beta_h F_L S_h - \sigma_h E_h - \mu_h E_h \; \frac{dI_h}{dt} = \sigma_h E_h - \gamma_h T_h - \delta_h I_h - \mu_h I_h \; \frac{dT_h}{dt} = \gamma_h T_h - k_2\delta_h T_h - \mu_h I_h - mT_h \; \frac{dP_h}{dt} = mT_h - \mu_h P_h \; \frac{dF_L}{dt} = \lambda I_h - \mu_F F_L \} \quad (2)$$

Steady States of Equilibrium

System (2) has two equilibrium points, namely, disease-free equilibrium point (DFE) and endemic equilibrium point (EE).

1. The disease-free equilibrium point is defined by

$$E_0 = (S_h^*, E_h^*, I_h^*, T_h^*, P_h^*, F_L^*)$$

At the disease-free equilibrium, there are no infection or recovery and thus filariform larvae are produced. Accordingly, at this point, I_h^* in System (2) must be zero; hence, the point is obtained as:

$$E_0 = \left(\frac{\propto_h}{\mu_h}, 0, 0, 0, 0, 0\right)$$

where $I_h^* = 0$

2. Endemic equilibrium Point (EE). At the endemic equilibrium point, all disease states in Equation (2) are considered positive and, consequently, R_h^* must be greater than zero for all states to be positive, i.e., $R_0 > 1$. We define this by:

$$E_1 = (S_h^{**}, R_h^{**}, I_h^{**}, T_h^{**}, P_h^{**}, F_L^{**})$$

We set the LHS of Equation (2) to be zero and by solving this, we obtain:

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$S_h^{**} = \frac{\propto_h + eT_h^{**}}{k_1\beta_h F_L^{**} + \mu_h}$ (3)

$E_h^{**} = \frac{k_1\beta_h F_L^{**} S_h^{**}}{\sigma_n + \mu_h}$ (4)

$I_h^{**} = \frac{\sigma_h E_h^{**} - \gamma_h T_h^{**}}{\sigma_n + \mu_h}$ (5)

$T_h^{**} = \frac{\mu_h I_h^{**} - \gamma_h T_h^{**}}{\gamma_n - m - k_2\delta_h}$ (6)

$P_h^{**} = \frac{mT_h^{**}}{\mu_h}$ (7)

$F_L^{**} = \frac{\varsigma T_h^{**}}{\mu_h}$ (8)

Stability Analysis and Basic Reproduction Number (R_0)

The basic reproduction number is defined as the average number of secondary infections caused by the emergence of an infectious individual with a completely susceptible population (Van den Driessche *et al.*, 2008). The method of Next Generation Matrix (Ebrima *et al.*, 2021) was used.

The model Equation (1) is rewritten starting with the new diseases in the system of equation:

$\frac{dB_h}{dt} = (1-\xi_h)\beta_h F_L S_h - \sigma_h E_h - \mu_h E_h \; \frac{dI_h}{dt} = \sigma_h E_h - \gamma_h T_h - \delta_h I_h - \mu_h I_h \; \frac{dF_L}{dt} = \Lambda I_h - \mu_F F_L \}$ (9)

From (9), f and v are deduced, where f refers to the new infections while v indicates other interactions in the infected compartment. This yields:

$f = (k_1\beta_h F_L S_h \; 0 \; 0)$ and $v = (\sigma_h E_h + \mu_h E_h \; \gamma_h T_h + \delta_h I_h + \mu_h I_h - \sigma_h E_h \; \mu_F F_L - \Lambda I_h)$

Now differentiate f and v partially to yield F and V respectively, that is:

$$F = \left(\frac{\partial f_1}{\partial B_h} \; \frac{\partial f_1}{\partial I_h} \; \frac{\partial f_1}{\partial F_L} \; \frac{\partial f_2}{\partial B_h} \; \frac{\partial f_2}{\partial I_h} \; \frac{\partial f_2}{\partial F_L} \; \frac{\partial f_3}{\partial B_h} \; \frac{\partial f_2}{\partial I_h} \; \frac{\partial f_3}{\partial F_L}\right) \quad \text{and}$$

$$V = \left(\frac{\partial v_1}{\partial E_h} \; \frac{\partial v_1}{\partial I_h} \; \frac{\partial v_1}{\partial F_L} \; \frac{\partial v_2}{\partial E_h} \; \frac{\partial v_2}{\partial I_h} \; \frac{\partial v_2}{\partial F_L} \; \frac{\partial v_3}{\partial E_h} \; \frac{\partial v_2}{\partial I_h} \; \frac{\partial v_3}{\partial F_L}\right)$$

$$F = (0 \; 0 \; k_1\beta_h S_h \; 0 \; 0 \; 0 \; 0 \; 0 \; 0)$$

$$V = (\sigma_h + \mu_h \; 0 \; 0 \; -\sigma_h \; \delta_h + \mu_h \; 0 \; 0 \; -\Lambda \; \mu_F) = (k_3 \; 0 \; 0 \; -\sigma_h \; k_4 \; 0 \; 0 \; -\Lambda \; \mu_F)$$

where $k_3 = \sigma_h + \mu_h$ and $k_4 = \delta_h + \mu_h$

$$V^{-1} = \frac{1}{|V|} . AdjV$$

$$V^{-1} = \left(\frac{1}{k_3} \; 0 \; 0 \; \frac{\sigma_h}{k_3 k_4} \; \frac{1}{k_4} \; 0 \; \frac{\Lambda\sigma_h}{k_3 k_4 \mu_F} \; \frac{\varsigma}{k_4 \mu_F} \; \frac{1}{\mu_F}\right)$$

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$$FV^{-1} = (0\ 0\ k_1\beta_h S_h\ 0\ 0\ 0\ 0\ 0\ 0)\left(\frac{1}{k_3}\ 0\ 0\ \frac{\sigma_h}{k_3k_4}\ \frac{1}{k_4}\ 0\ \frac{\Lambda\sigma_h}{k_3k_4}\ \frac{\Lambda}{k_4\mu_F}\ \frac{1}{\mu_F}\right)$$

$$\left(\frac{k_1\beta_h S_h^* \Lambda T_h}{k_3k_4\mu_F}\ \frac{k_1\beta_h S_h}{k_3\mu_F}\ \frac{k_1\beta_h S_h}{\mu_F}\ 0\ 0\ 0\ 0\ 0\ 0\right)$$

$$R_0 = e(FV^{-1}) = |FV^{-1} - \Lambda I| = 0$$

$R_0 = \frac{k_1\beta_h\varsigma\sigma_h S_h^*}{k_3k_4\mu_F} > 1$ (10)

R_0 is positive, $R_0 > 1 \Rightarrow$ Endemic Equilibrium

Sensitivity Analysis

In this section, we determine the significant parameters that increase or decrease the burden of the disease. To do this, we will consider the parameters involved in R_0 and compute:

$$\psi_P R_0 = \frac{\partial R_0}{\partial P} \times \frac{P}{R_0}$$

where P represents the parameters in R_0

Hence, $\psi_{k_1}R_0 = 1$, $\psi_{\beta_h}R_0 = 1$, $\psi_{\varsigma}R_0 = 1$, $\psi_{\delta_h}R_0 = 1$, $\psi_{k_3}R_0 = -1$, $\psi_{k_4}R_0 = -1$, $\psi_{\mu_F}R_0 = -1$

Table 3: Sensitivity Analysis

Parameter	Description	Value	Sensitivity Index
k_1	Preventive factor due to WASH (ξ_h)	0.9	+1
β_h	Rate of transmission of humans from susceptible to exposed	0.9153	+1
α_h	Recruitment rate of human	400	+1
δ_h	Death rate of human due to infection	0.002	+1
k_3	Rate of transmission of human from exposure to infectious (σ_h)	0.023644	−1
k_4	Natural death rate of human (μ_h)	0.002044	−1
μ_F	Natural death rate of Filariform Larvae	0.2	−1

where k_1 = 1-ξ_h, k_3= σ_h + μ_h, k_4= δ_h + μ_h

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In Table 3, the parameters with positive sensitivity index are those parameters that have great impact on the expansion or spread of the disease in the community because their values are increasing, i.e., the increase in the parameters will result in the increase in the burden of the disease. A reduction of these parameters will also reduce the spread of the diseases. On the other hand, the parameters with negative sensitivity index have the capacity to minimize or reduce the burden of the disease.

Numerical Simulation of the Mathematical Modelling

Figures 1, 2, 3, 4, and 5 display the numerical simulation results, accordingly. The behavior of every population of values displayed in Table 2 is depicted in Figure 1. There was a steady rise in the compartment containing vulnerable people and filariform larvae. Additionally, there was stability in other compartments and a gradual rise in the human compartment that was exposed. Figure 2a shows how the susceptible humans rose or increased during the first few days but then progressively decreased as a result of their constant contact with the filariform larvae in the soil, which increased the rise of the filariform larvae compartment (Figures 2b and 2c). Additionally, we noticed a gradual rise in the infected and exposed human compartments followed by a rapid surge. Figure 3a shows that when 10 individuals are added to the population, there is a significant increase in the filariform larvae compartment and stability in every other compartment. When 400 individuals are added to the community, Figure 3b shows a rise in filariform larvae, vulnerable humans, and exposed compartments while maintaining stability in all other compartments. Similar to this, Figure 3c shows stability in all other compartments but a steady increase in sensitive humans, filariform larvae, and exposed compartments after 900 individuals were added to the population. Additionally, there was a consistent rise in Figure 4a and Figure 4b in the filariform larvae and susceptible human compartments, whereas in Figure 4c, the treatment human compartments gradually increased over the course of the first few days before stabilizing. Figure 5a shows that the susceptible human and filariform larvae compartments were constantly growing, but Figures 5b and 5c show that the treated human compartment is much more stable.

Impact of the Rate of Behavior of All the Populations

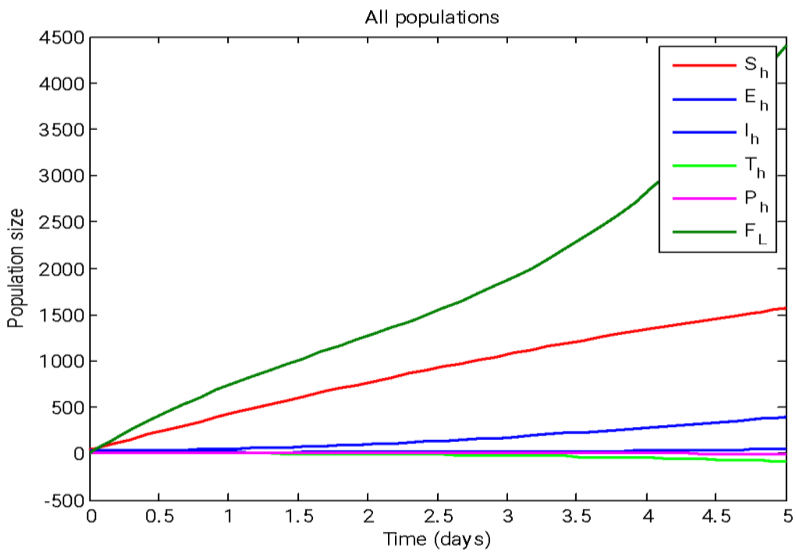

Figure 1: Illustrate the behavior of all the populations of values shown on the Table 3.

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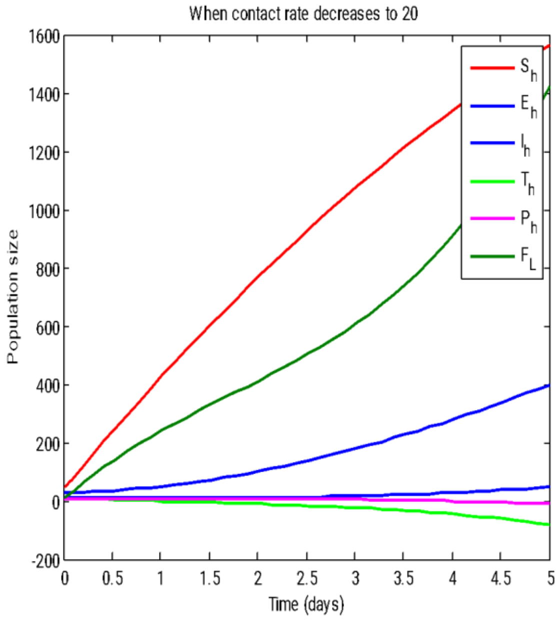
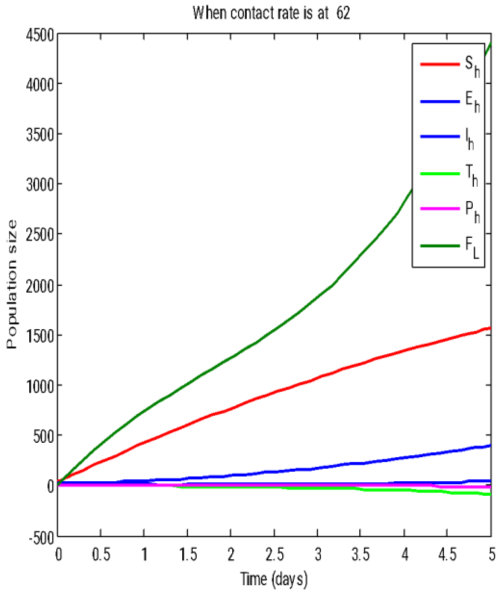
Impact of the Rate at Which Human Contact Filariform Larvae



(a)



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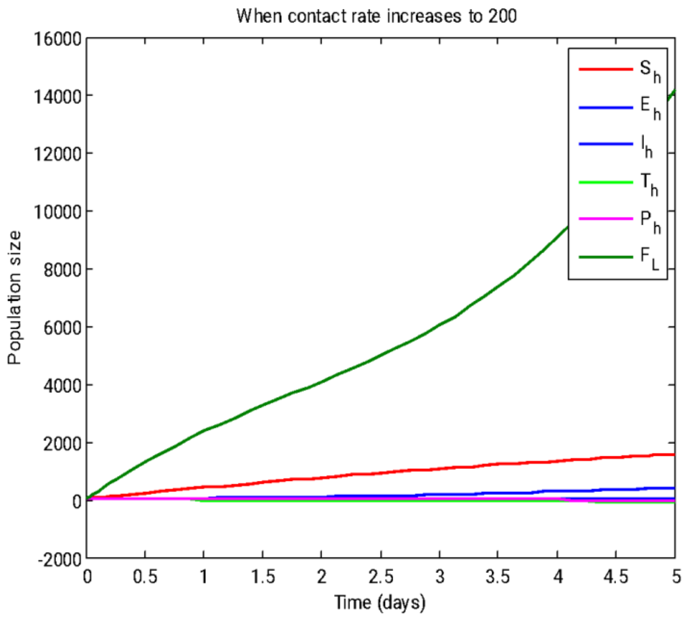

(c)

Figure 2: Shows the rate at which contact rate was varied from 20 to 200 with filariform larvae and all other parameters remain the same as given in Table 3.2.

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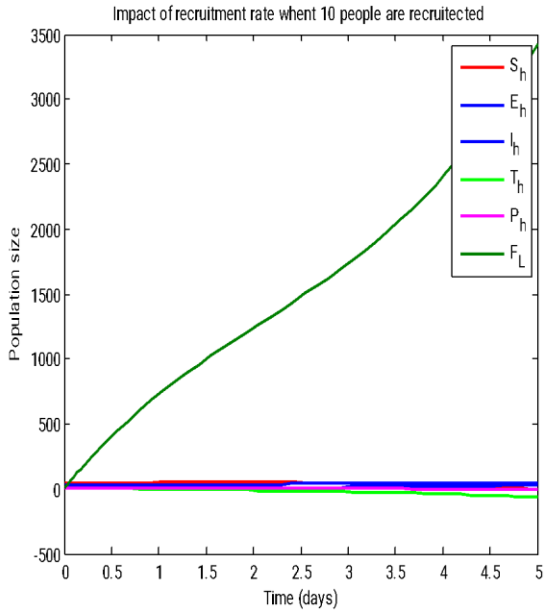
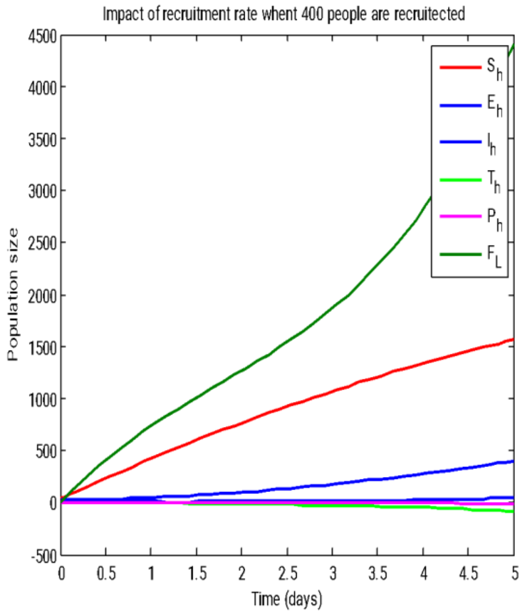
Impact of Recruitment



(a)



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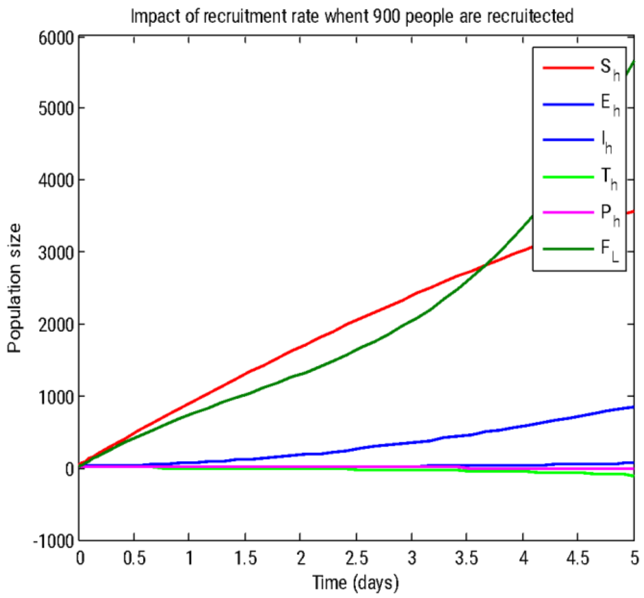

(c)

Figure 3: Graphs showing the effect of recruitment into the entire population

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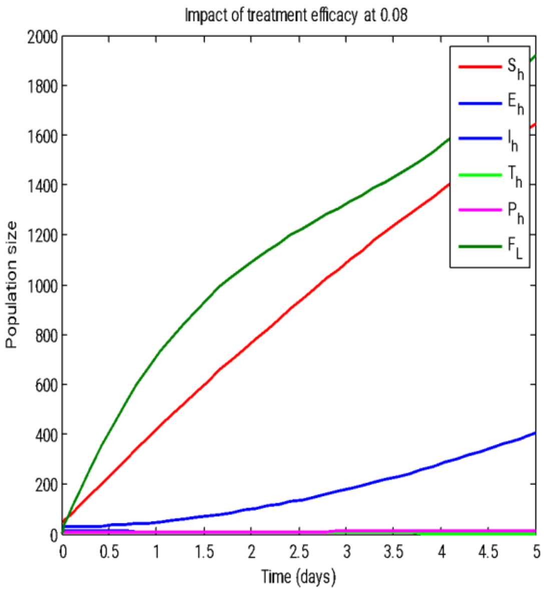
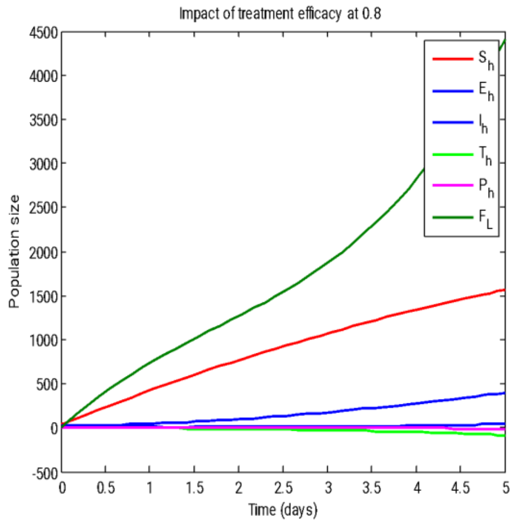
Impact of Treatment Efficacy



(a)



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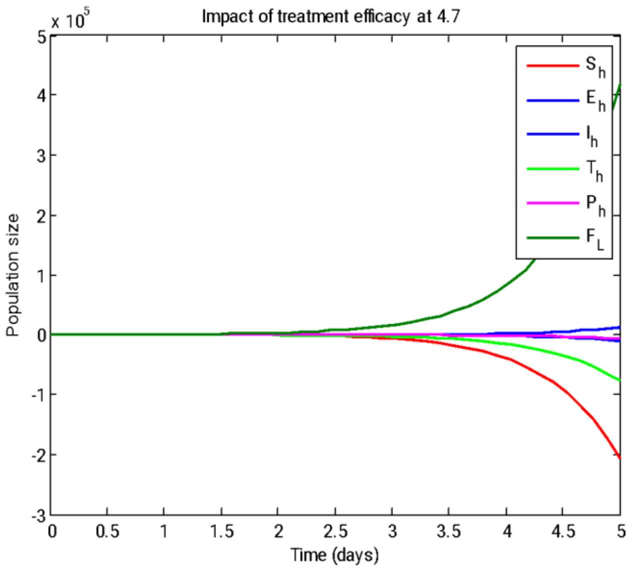

(c)

Figure 4: The plots of the treatment rate efficacy varied from 0.08 to 4.7

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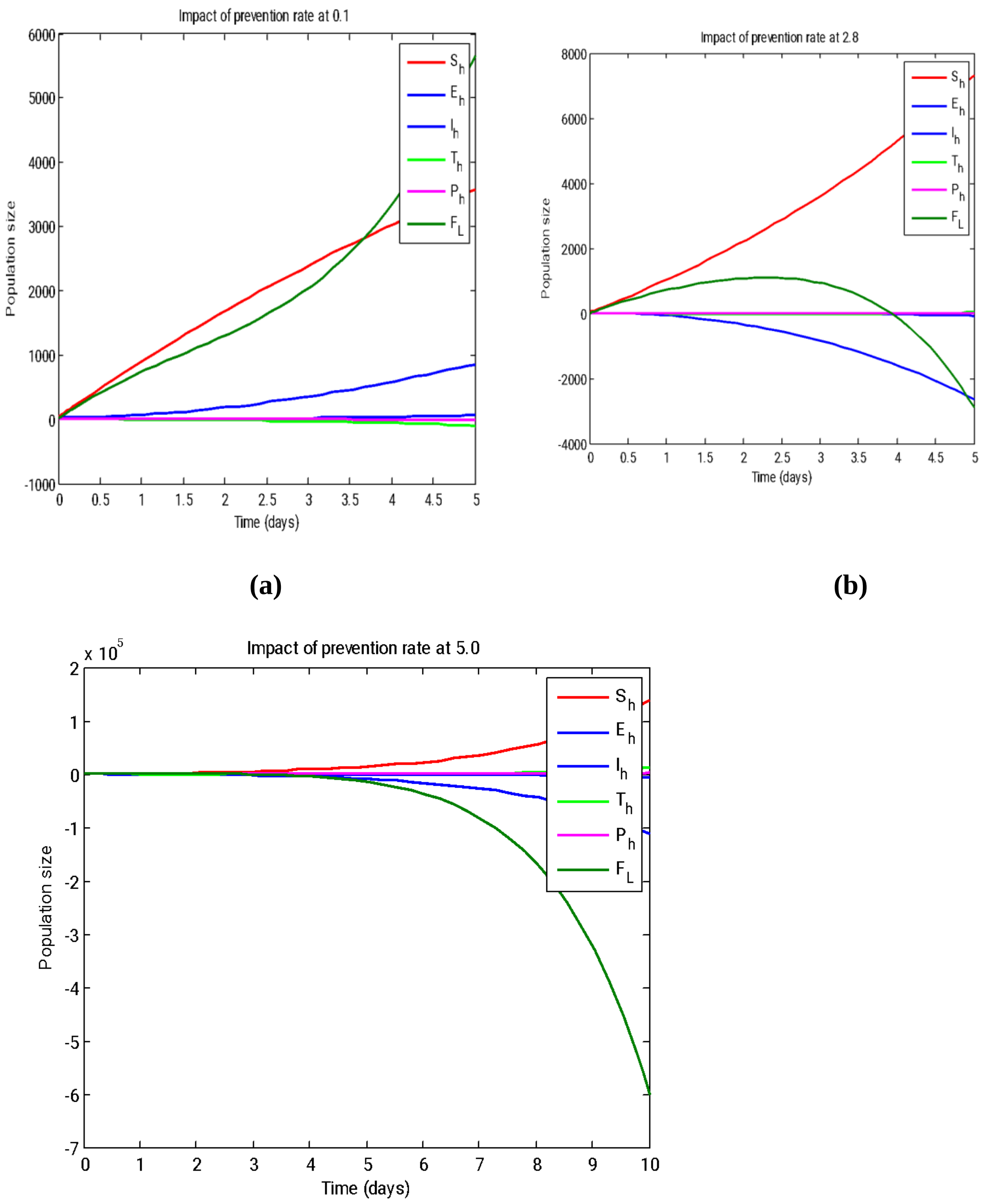
The Effect of Prevention Measure by Wash



(a) **(b)**

(c)

Figure 5: Demonstrate the prevention measure on the entire population

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DISCUSSION

Validating the analytical conclusions acquired using numerical simulation is helpful and occasionally necessary in mathematical modeling of epidemiology. Additionally, whenever a model is or is not formulated in a mathematical sense, it is typically necessary to verify that the abstraction of the model and the formulation of the mathematical language agree. This is accomplished by applying mathematical concepts and properties like existence and uniqueness of solutions, equilibrium states, etc. Additional analysis, including a threshold parameter for the spread of diseases, control criteria, and an examination of the most vulnerable settings that could trigger an epidemic of diseases, may be conducted based on interest. A mathematical model was put out in this study to explain *Strongyloides stercoralis* dynamics. Investigating characteristics like existence and uniqueness of solution demonstrates that the models were well posed in the biological and mathematical senses. A disease control parameter popularly referred to as reproduction number (R_0) was established, which proved the chances for successful eradication of *Strongyloides stercoralis* outbreak.

In order to verify the validity and competency of the simulation results with the biological framework for the suggested models, the initial values for the model's parameters were taken from the literature; in cases where values were not accessible, assumptions were made. Table 2 displays the initial values that were assigned. Two equilibrium states for the model—disease-free equilibrium and endemic equilibrium—were determined by the equilibrium analysis. for the populace of humans. It is interesting to note that these outcomes support the findings of Ebrima *et al.* (2021) about *Strongyloides stercoralis*. The findings are interpreted as follows: in a situation in which there will be no parasites in the society or community, and in a state in which sickness persists in the human population due to exposure to filariform larvae.

Equations 1 and 2 yield the threshold parameter results for *Strongyloides stercoralis* management that is necessary for success. The inference is that, if equilibrium (ii) can be well controlled (i.e., the capacity to minimize infection and treat those who are already affected), society will enjoy good health. An effective strategy to control the spread of *Strongyloides stercoralis* is to isolate or restrict the movement of affected patients while they are undergoing treatment. The force of infection must, in mathematical terms, be less than the rate of clearance.

The values of the model parameters in Table 3.2 were used to run various numerical simulations using the ordinary differential equation (ODE) in MATLAB. While some of the parameters are derived from real-world data, many are derived from previously published literature and are properly attributed. Based on what is widely known about the dynamics of the examined population and the parasite, further parameters are estimated for convenience. Figures 1, 2, 3, 4, and 5 display the numerical simulation results, accordingly.

Figure 1 shows the behavior of all the populations of values shown on Table 2. A continuous increase in the filariform larvae and susceptible humans compartment was observed. There was a steady rise in the exposed human compartment and stability in other compartments. The study revealed the behaviors of each compartment of the model in the study population.

Figure 2a shows how the susceptible humans rose or increased during the first few days, but then progressively decreased as a result of their constant contact with the filariform larvae in the soil, which increased the rise of the filariform larvae compartment (Figures 2b and 2c). Due to the introduction of the parasite, we also saw a gradual rise in the exposed and infected human

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compartments followed by a rapid rise, both of which later suffered a slow rise as the disease progressed. This discovery demonstrated that increased exposure to filariform larvae or interaction with vulnerable humans can cause parasite infection.

Figure 3a shows that when ten (10) individuals are added to the population, there is a significant increase in the filariform larvae compartment and stability in every other compartment. When 400 individuals are added to the community, Figure 3b shows a rise in filariform larvae, vulnerable humans, and exposed compartments while maintaining stability in all other compartments. Similar to this, Figure 3c shows stability in all other compartments but a steady increase in sensitive humans, filariform larvae, and exposed compartments after 900 individuals were added to the population. This demonstrates that the number of persons within a population increases the amount of susceptible humans exposed to filariform larvae.

Additionally, when there was little or no public health awareness or education, the susceptible human and filariform larvae compartments in Figures 4a and 4b steadily increased, whereas in Figure 4c, the treatment human compartments gradually increased over the course of the first few days before stabilizing. This demonstrates that a significant increase in public health education can result in a decrease in the number of susceptible humans coming into contact with filariform larvae, which is what causes the parasite to infect humans. It also maintains stability in the human population that has received this education.

Additionally, we saw the impact of the treatment in Figure 5, where the efficacy of the treatment rate ranged from 0.1 to 5.0. Here, we investigate the potential effects of treating more diseased persons on both the overall number of infected humans and the rates at which the infections are produced. Figure 5a shows that for the simple reason that there were little or no preventive measures in place to lower the rate of human-flagelliform larvae interaction, the number of susceptible human and filariform larvae compartments increased continuously. However, in Figures 5b and 5c, the treatment human compartment remains rather stable due to the introduction of a higher prevention rate, which in turn led to a greater decline in the filariform larvae compartment. This demonstrated that individuals will continue to get infected or re-infected even when treatment is due without combining with preventive strategies like WASH. WASH is a preventive mechanism for controlling the spread of *Strongyloides stercoralis*. As a result, the susceptible and treated individuals should be educated on WASH procedures to effectively curtail the spread of the disease.

The results of the sensitivity analysis in Table 3 revealed that the parameters k_1, β_h, α_h, and δ_h have positive indices and therefore are each directly proportional to the value of R_0. Thus, increasing the value of any of these parameters will lead to the disease remaining endemic within the studied population and vice versa. However, parameters k_3, k_4, and μ_F each have a negative sensitivity index, which means that each of them varies inversely as the value of R_0. Therefore, a continuous decrease in these parameters will lead to a continuous decrease in the burden of the disease, and hence contribute to the elimination of the parasite and vice versa.

CONCLUSION

A mathematical model has been presented to explain both the dynamics of the free-living filariform larvae and the transmission dynamics of the human disease (*Strongyloides stercoralis*). By including the treated human compartment and preventative mechanisms

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through public health awareness and hygiene (WASH), attention is directed to controls within the human subpopulation. After obtaining the endemic and disease-free equilibrium points, local stabilities were examined. When there is a distinct endemic equilibrium point, $R_0 > 1$ was established and it is confirmed that the endemic equilibrium is locally asymptotically stable ($R_0 > 1$). We used a numerical simulation to verify these analytical findings. The next generation matrix method was also used to get the model's fundamental reproduction number. A completely eradicable disease could result from eliminating the parasites in a little amount of time through better personal cleanliness and a more hygienic environment that prevents the reproduction and survival of filariform larvae. To assist decision makers in understanding the most successful tactics and associated costs for controlling the spread of this parasite, additional research on optimal control analysis and cost effectiveness is advised. Further recommended is a worldwide stability analysis to guarantee the total eradication of this parasite.

CONTRIBUTION TO KNOWLEDGE

1. The study incorporated public health education which is the compartment (P_h) and also the compartments for the filariform larvae (F_L) based on the transmission of the diseases in the compartmental chart for the mathematical modelling of *Strongyloides stercoralis*.
2. This research work also provided database information about mathematical modeling and analysis of transmission dynamics and control of *Strongyloides stercoralis* in Obi Local Government Area of Nasarawa State, which other researchers can use for further studies.

Conflicts of Interest: The authors declare no conflict of interest.

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