**ANALYSIS OF TRANSMISSION DYNAMICS AND CONTROL OF *Strongyloides stercoralis* USING MATHEMATICAL MODELING IN NASARAWA STATE**

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**ABSTRACT**

*Strongyloides stercoralis* is an intestinal nematode that causes a parasitic infection called strongyloidiasis in humans. This study presents a mathematical modeling and analysis of transmission dynamics and control of *Strongyloides stercoralis* in Nasarawa State. 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. The basic reproduction number, R0, is computed and used as a threshold value using the next generation matrix method. It is established that the unique endemic equilibrium point is locally asymptotically stable provided R0 >1. Additionally, to ascertain the impact of various parameter values on the growth of *Strongyloides stercoralis*, a sensitivity analysis of R0 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, Nasarawa State.

**INTRODUCTION**

*Strongyloides stercoralis* is an intestinal nematode that causes a parasitic infection called strongyloidiasis in humans. It is endemic in humid tropical regions that include Africa, Latin America and Southern Asia ((Ali *et al*., 2023)). Among the public health important STHs classified as neglected tropical diseases (NTDs), *S. stercoralis* infection is the most overlooked and its prevalence is greatly underestimated (Bala & Yakubu, 2010). It is estimated that around 30–100 million people are infected in endemic areas globally, with most of them living in tropical and subtropical countries (Edema *et al.,* 2021). The disease is mainly associated with low socioeconomic level communities due to poor sanitation (Peter & Kamath, 2019).

In sub-Saharan Africa, more than 200 million people have been infected with hook worm and 90 million of them were children. In Ethiopia, more than 11 million peoples 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 skin (Ezema *et al.,* 2025). *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 (Ezema *et al.,* 2025).

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, 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 policy makers 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 (Sh), exposed humans (Sh), infected humans (Ih) and treatment humans (Th). We incorporated the public health Education human on drug treatment which is the compartment (Ph) and also the compartments for the Filariform larvae (FL) based on the transmission of the diseases was added.

**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 becomes exposed to the disease.
5. Treated human can become susceptible again on contact with Filariform Larvae

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

All recruitment is carried out in the (susceptible compartment) which later moved to the (exposed compartment) which the human population is been exposed with the disease. The infectious class compartment () is where the human population come in contact with the Filariform Larvae (). The Filariform Larvae is the only means through which susceptible humans becomes exposed to the disease. Infectious humans are treated which is the class (Treatment compartment) through Public Health Education compartment ().



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

**Table 1. Variable Description**

|  |  |
| --- | --- |
| **Variable**  | **Description** |
|  | Susceptible Human |
|  | Exposed Human |
|  | Infected Human |
|  | Treated Human |
|  | Public Health Education Human |
|  | Filariform Larvae |

**Table 2. Parameter Description**

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

 **Model Equation**

The model is represented by the following system of ODEs:

With initial conditions and

**Data Analysis**

The basic reproduction number R0 was determined using the next generation matrix and the numerical analysis of the model was conducted using MATLAB.

**Results**

**Mathematical Analysis of the Model**

 (1)

Let

So that

 (2)

**Steady States of Equilibrium**

The 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

At the disease- free equilibrium, there are no infection or recovering and thus Filariforn Laevae is produced. Accordingly, at this point, in the system (2) must be zero hence, the point is obtained as:

Where

1. Endemic equilibrium Point (EE). At the endemic equilibrium point, all disease states in equation (2) are considered positive and consequently must be greater than zero for all states to be positive, i.e . We define by

We set the LHS of equation (2) to be zero and solving we obtain

 (3)

 (4)

 (5)

 (6)

 (7)

 (8)

**Stability Analysis and Basic Reproduction Number**

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

 (9)

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

 and

Now differentiate and partially to yield and respectively that is

 and

Where and

 (10)

 is positive, 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 and compute;

Where P represents the parameters in

Hence , , , , , ,

**Table** **3. Sensitivity Analysis**

|  |  |  |  |
| --- | --- | --- | --- |
| **Parameter** | **Description**  | **Value** | **Sensitivity Index** |
|  | Preventive factor due to WASH ( | 0.9 |  |
|  | Rate of transmission of humans from susceptible to exposed | 0.9153 |  |
|  | Recruitment rate of human | 400 |   |
|  | Death rate of human due to infection | 0.002 |  |
|  | Rate of transmission of human from exposure to infectious ( | 0.023644 |  |
|  | Natural death rate of human () | 0.002044 |  |
|  | Natural death rate of Filariform Larvae | 0.2 |  |

 Where = 1-, = + , = +

In table 3, the parameter 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 capacity of minimizing or reducing 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 increase 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.

1. **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 3.2

1. **Impact of the Rate at Which Human Contact Filariform Larvae**

****

 (a) (b)

****

 **(c)**

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

1. **Impact of Recruitment**



 (a) (b)



(c)

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

1. **Impact of Treatment Efficacy**



 **(a) (b)**



 **(c)**

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

1. **The Effect of Prevention Measure by Wash**

 **(a) (b)**



 **(c)**

Figure 5: Demonstrate the prevention measure on the entire population

**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. An establishment of a disease control parameter popularly referred to as reproduction number (R0) 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's 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 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 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 of with preventive strategies like WASH. WASH is a preventive mechanism in 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.

Results of the sensitivity analysis in Table 3 revealed that, the parameters , , , and have positive indices and therefore, are each directly proportional to the value of R0. Thus, increasing the value of any of these parameters will lead to the disease remaining endemic within the studied population and vice versa. However, the parameters , , and have each a negative sensitivity index, which means that each of them varies inversely as the value of R0. 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 include the treated human compartment and preventative mechanisms 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, R0 >1 was established and it is confirmed that the endemic equilibrium is locally asymptotically stable (R0 >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. Furthermore recommended is a worldwide stability analysis to guarantee the total eradication of this parasite.

**Contribution To Knowledge**

1. The study incorporated the public health Education which is the compartment (Ph) and also the compartments for the Filariform larvae (FL) based on the transmission of the diseases in the compartmental Chart for the Mathematical Modelling of *Strongyloides stercoralis*.
2. This research work also provided data base information about mathematical modeling and analysis of transmission dynamics and control of *Strongyloides stercoralis* in Nasarawa State, which other researchers can use for further studies.

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

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