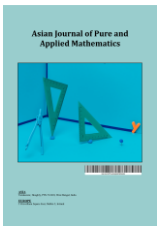

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Modeling Pediculosis Transmission with Infection Awareness for Control

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

In this paper, a mathematical model for pediculosis infection was developed and analysed. The model was designed by dividing the system into six compactments leading to a system of ordinary differential equations. The model is built on the assumption that some of those with pediculosis infection are aware of the disease while others are not. Conditions are derived for the positivity of the solution, and the existence of disease free and endemic equilibria. It shows that the disease can be eliminated under certain conditions. The model equation was solved using the homotopy perturbation method and numerical simulation were carried out to investigate the effects of some of the transmission parameters on the dynamics of the infection. The results showed that with effective treatment, pediculosis can be eradicated from a human population.

Keywords: Pediculosis disease; mathematical model; awareness infection; transmission dynamics and homotopy pertbation method (HPM).

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1 Introduction

Globally, there are hundreds of diseases caused by different parasites and Pediculus (Lice) is one of them. Pediculus are obligate exclusively human ectoparasites and are source of annoying infestations worldwide. [1]. According to history, humans acquired lice from gorillas several million years ago [2]. The oldest known fossils of louse eggs (nit) are almost 10,000 years old, though there is much less occurrence information for pubic lice than for head and body lice [3]. Pediculus belongs to the kingdom of Animalia, the phylum of Arthropoda the class of Insecta, the order of Siphunculata, the family of Anoplura, the genus Pediculidae and the species is Humanus (corporis, capitis and pubis) [4]. Pediculosis (louse infestation) is a disease caused by pediculus humanus. Pediculus humanus is a small insect with a large abdomen and legs equipped with sharps claws for holding hair and clothing fibers. The head of the louse is slightly narrower than the body. They do not have wings like other insect but they have piercing mouthparts for digging the skin and draining blood. This disease called pediculosis infects millions of school-age children between the ages of three (3) to twelve (12) every year in both developed and developing countries, because of the crowding and non-hygiene condition they may be experiencing [5]. It is also common for several members of the same household to be affected. Infestations are more common in the warmer months, as well as in areas with higher humidity [6]. Head lice cross all socioeconomic barriers, whereas body lice more commonly affect the homeless and displaced [7-9].

The rate of infestation of pediculosis can be controlled by treatment of those infected. Awareness of the possibility of infection can also help in taking deliberate step in preventing or eliminating infection. In this paper, a mathematical model on the transmission dynamics of pediculosis infection has been developed. The model incorporates the awareness of the infection.

2 Problem Formulation

Pediculosis is a disease neglected by many due to its non-ability to kill but it causes inconvenience and morbidity to the environment. There is a critical need to understand its transmission dynamics and the effect of certain factors like treatment and awareness on the spread of the disease. Moreover, even though scholarly works exist on pediculosis infection, there is limited work on its modeling and the effect on the environment Chukwu [10] formulated a mathematical model of the system of equation describing the dynamics of pediculosis transmission and modeled the disease into five systems of ordinary differential equation a varying population and discovered that the disease can be contacted via person to person contact or other object used by the infected person and recommend more increase in awareness.The modified model is the continuation of the work of Chukwu [10] to include awareness of infection.

2.1 Assumptions of the modified model

1. There is no disease induced rate because the disease does not kill.
2. Without treatment, the disease persists.
3. The recovered population can be susceptible.
4. At any stage, there can be natural death rate which may differ based on compartments.
5. Any other disease generated as a result of scratch/persistence is neglected.
6. Every immigrant without coming in contact with the insect or infected person remain uninfected.
7. The recovered individuals can be susceptible but are now aware of the infection
8. Some members of the susceptible population are aware, while others are not aware.

2.2 Compartments of the modified model

The total population size is sub-divided into six epidemiological classes as tabulated below:

Table 1. Compartment of the model

Variables	Description
S_A(t)	Susceptible population of those who are aware of pediculosis infection
S_u(t)	Susceptible population of those who are not aware of pediculosis infection
I(t)	The infected population of humans who can transmit the disease to others
I_T(t)	The population of the infected and undergoing treatment
R(t)	The population of recovered after treatment

2.3 Notations of the modified model

Table 2. Parameter of the Model

Parameter	Description
β	The rate at which susceptible individual get infected with pediculosis infection
ρ	Movement rate for individual who stopped adhering to preventive measures
ϕ	Movement rate from R to S_A Class
α	Rate of progression from I to I_T and I_{NT}
θ	Proportion of individual moved to the treatment class
$(1-\theta)$	Proportion of individual not moved to the treatment class
μ	Natural death rate associated with each of the compartment (class)
Λu	Recruitment number of individual who are not aware of the pediculosis
Λ_A	Recruitment number of individual who are aware of pediculosis infection
ε	The rate at which individual recover from the pediculosis infection
τ	Movement rate for unaware to awareness

2.4 Description of the model

In this work, the manifestation of pediculosis in the population is divided into six compartments which gives six differential equations according to their epidemiological state which are: the susceptible who are aware $S_A(t)$, who are not aware $S_u(t)$, the infected I(t), the infected but treated $I_T(t)$ and the recovered R(t).

The susceptible class is the set of people that have not come in contact with the pediculosiss, may or may not be aware of the possibility of pediculosis infection. They are the people coming into the population. The susceptible population that is aware is assumed to be taking preventive measure. The infected class is the population that has gotten the disease and can transmit it to other, the infected and treated set of people that are infected and are receiving treatment to recover, the infected and not treated people are those that are infected but are yet to receive treatment which the disease remain with them (persevere), while the recovered class is the set of people that have recovered from the disease due to treatment. The natural death μ can take life at any time.

2.5 The flow diagram of the modified model

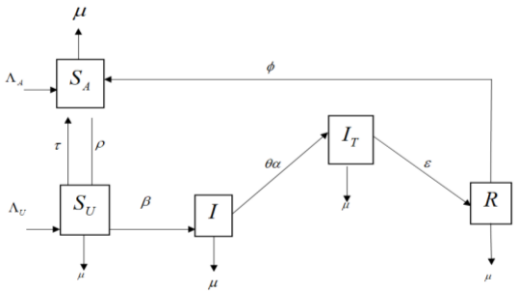

Fig. 1. Flow diagram of the modified model

2.6 The model equations

Based on our assumptions; variables and parameters on Tables 1 and 2 and the flow Diagram on Fig. 1, the following equations where derived for the modified model.

$$\frac{dS_A}{dt} = \Lambda_A + \tau S_u + \phi R - \rho S_A - \mu S_A \tag{1}$$

$$\frac{dS_u}{dt} = \Lambda_u + \rho S_A - \tau S_u - \mu S_u - \beta S_u I \tag{2}$$

$$\frac{dI}{dt} = \beta S_u I - (\mu + \alpha) I \tag{3}$$

$$\frac{dI_T}{dt} = \theta \alpha I - (\varepsilon + \mu) I_T \tag{4}$$

$$\frac{dR}{dt} = \varepsilon I_T - (\mu + \phi) R \tag{5}$$

3 Analysis of Results

Here, we will analyze the present model in order to understand the transmission level of pediculosis and verify if the disease can die off or not.

3.1 The disease-free equilibrium (DFE)

This is a situation where is no infection; the population is absent of pediculosis, so no one is infected or recovered. The disease-free equilibrium point is gotten by setting

$$\frac{dS_A}{dt} = \frac{dS_u}{dt} = \frac{dI}{dt} = \frac{dI_T}{dt} = \frac{dR}{dt} = 0, \tag{6}$$

and letting the infected classes equal zero then

$$I^* = 0\,, I_T^* = 0\,,\ R^* = 0$$

hence equation (1)–(5) reduces to

$$\Lambda_A + \tau S_u^* + \phi R^* - (\rho + \mu) S_A^* = 0 \tag{7}$$

$$\Lambda_u + \rho S_A^* - (\tau + \mu) S_u^* - \beta S_u^* I^* = 0 \tag{8}$$

equation (7) and (8) can be rewritten as

$$\tau S_u^* - (\rho + \mu) S_A^* = -\Lambda_A \tag{9}$$

$$-(\tau + \mu) S_u^* + \rho S_A^* = -\Lambda_u \tag{10}$$

equation (9) and (10) can be rewritten as

$$(\rho + \mu) S_A^* - \tau S_u^* = \Lambda_A \tag{11}$$

$$-\rho S_A^* + (\tau + \mu) S_u^* = \Lambda_u \tag{12}$$

Multiply equation (11) by ρ

$$\rho(\rho + \mu) S_A^* - \rho\tau S_u^* = \rho\Lambda_A \tag{13}$$

Multiply equation (12) by $(\rho + \mu)$

$$-\rho(\rho + \mu) S_A^* + (\rho + \mu)(\tau + \mu) S_u^* = (\rho + \mu)\Lambda_u \tag{14}$$

$$\left[(\rho + \mu)(\tau + \mu) - \rho\tau\right] S_u^* = \rho\Lambda_A + (\rho + \mu)\Lambda_u \tag{15}$$

$$\left[\rho\tau + \rho\mu) - \tau\mu + \mu^2 - \rho\tau\right] S_u^* = \rho\Lambda_A + (\rho + \mu)\Lambda_u \tag{16}$$

$$S_u^* = \frac{\rho\Lambda_A + (\rho + \mu)\Lambda_u}{\mu^2 + (\rho + \tau)\mu} \tag{17}$$

Multiply through by

$$(\tau + \mu) \tag{18}$$

$$(\tau + \mu)(\rho + \mu) S_A^* - \tau(\tau + \mu) S_u^* = (\tau + \mu)\Lambda_A \tag{19}$$

Multiply through by τ

$$-\tau\rho S_A^* + \tau(\tau + \mu) S_u^* = \tau\Lambda_u \tag{20}$$

$$\left[(\tau + \mu)(\rho + \mu) - \tau\rho\right] S_A^* = (\tau + \mu)\Lambda_A + \tau\Lambda_u \tag{21}$$

$$S_A^* = \frac{(\tau + \mu)\Lambda_A + \tau\Lambda_u}{\mu^2 + (\rho + \tau)\mu} \tag{22}$$

The disease-free equilibrium

$$= \left(S_A^*, S_u^*, 0,0,0,0\right)$$
$$= \left(\frac{(\tau+\mu)\Lambda_A + \tau\Lambda_u}{\mu^2 + (\rho+\tau)\mu}, \frac{\rho\Lambda_A + (\rho+\mu)\Lambda_u}{\mu^2 + (\rho+\tau)\mu}, 0,0,0,0 \right) \quad (23)$$

3.2 Local stability of disease-free equilibrium

The disease-free equilibrium points for the system (1) to (5) is locally asymptotically stable if $R_0<1$ and unstable if $R_0>1$

The Jacobian Matrix of the model is given by

$$J_P = \begin{pmatrix} \frac{\partial f_1}{\partial S_A} & \frac{\partial f_1}{\partial S_U} & \frac{\partial f_1}{\partial I_T} & \frac{\partial f_1}{\partial I} & \frac{\partial f_1}{\partial I_{NT}} & \frac{\partial f_1}{\partial R} \\ \frac{\partial f_2}{\partial S_A} & \frac{\partial f_2}{\partial S_U} & \frac{\partial f_2}{\partial I_T} & \frac{\partial f_2}{\partial I} & \frac{\partial f_2}{\partial I_{NT}} & \frac{\partial f_2}{\partial R} \\ \frac{\partial f_3}{\partial S_A} & \frac{\partial f_3}{\partial S_U} & \frac{\partial f_3}{\partial I_T} & \frac{\partial f_3}{\partial I} & \frac{\partial f_3}{\partial I_{NT}} & \frac{\partial f_3}{\partial R} \\ \frac{\partial f_4}{\partial S_A} & \frac{\partial f_4}{\partial S_U} & \frac{\partial f_4}{\partial I_T} & \frac{\partial f_4}{\partial I} & \frac{\partial f_4}{\partial I_{NT}} & \frac{\partial f_4}{\partial R} \\ \frac{\partial f_5}{\partial S_A} & \frac{\partial f_5}{\partial S_U} & \frac{\partial f_5}{\partial I_T} & \frac{\partial f_5}{\partial I} & \frac{\partial f_5}{\partial I_{NT}} & \frac{\partial f_5}{\partial R} \\ \frac{\partial f_6}{\partial S_A} & \frac{\partial f_6}{\partial S_U} & \frac{\partial f_6}{\partial I_T} & \frac{\partial f_6}{\partial I} & \frac{\partial f_6}{\partial I_{NT}} & \frac{\partial f_6}{\partial R} \end{pmatrix} \quad (24)$$

At DFE, we had

$$F_0^* = \left(S_A{}^*, S_U{}^*, I^*, I_T, I_{NT}{}^* R^*\right) = \left(\frac{(\tau+\mu)\Lambda_A + \tau\Lambda_u}{\mu^2 + (\rho+\tau)\mu}, \frac{\rho\Lambda_A + (\rho+\mu)\Lambda_u}{\mu^2 + (\rho+\tau)\mu}, 0,0,0,0 \right) \quad (25)$$

Let

$$K_1 = S_u^* = \frac{\rho\Lambda_A + (\rho+\mu)\Lambda_u}{\mu^2 + (\rho+\tau)\mu} \quad (26)$$

$$J^0 = J_P(E_0^*) = \begin{pmatrix} -(\rho+\mu) & \tau & 0 & 0 & 0 & \phi \\ \rho & -(\mu+\tau) & -\beta(k_1) & 0 & 0 & 0 \\ 0 & 0 & -(\mu+\alpha) & 0 & 0 & 0 \\ 0 & 0 & \theta\alpha & -(\varepsilon+\mu) & 0 & 0 \\ 0 & 0 & (1-\theta)\alpha & 0 & -\mu & 0 \\ 0 & 0 & 0 & \varepsilon & 0 & -(\mu+\phi) \end{pmatrix} \quad (27)$$

$$\left|J^0-\lambda I\right|=\begin{vmatrix} -(\rho+\mu)-\lambda & \tau & 0 & 0 & 0 & \phi \\ \rho & -(\mu+\tau)-\lambda & -\beta(k_1) & 0 & 0 & 0 \\ 0 & 0 & -(\mu+\alpha)-\lambda & -\theta\alpha & -(1-\theta)\alpha & 0 \\ 0 & 0 & \theta\alpha & -(\varepsilon+\mu)-\lambda & 0 & 0 \\ 0 & 0 & (1-\theta)\alpha & 0 & -\mu-\lambda & 0 \\ 0 & 0 & 0 & \varepsilon & 0 & -(\mu+\phi)-\lambda \end{vmatrix} \quad (28)$$

$$\left(-(\rho+\mu)-\lambda\right)\left(-(\mu+\tau)-\lambda\right)\left(-(\mu+\alpha)-\lambda\right)\left(-\varepsilon+\mu-\lambda\right)\left(-\mu-\lambda\right)\left(-\mu+\phi-\lambda\right)=0 \quad (29)$$

$$\lambda_1=(-\rho+\mu),\ \lambda_2=-(\mu+\tau),\ \lambda_3=-(\mu+\alpha), \quad (30)$$

$$\lambda_4=-(\rho+\mu),\ \lambda_5=-(\mu+\phi) \text{ and } \lambda_6=-(\varepsilon+\mu) \quad (31)$$

Therefore, DFE is locally asymptotically stable because $R_0 < 1$

3.3 Local stability of the endemic equilibrium

The dynamics of a disease is known by the stability at the endemic equilibrium. We will investigate the stability of the model equation at the endemic equilibrium. The endemic equilibrium is locally asymptotically stable if $R_0 > 1$.

3.4 The Basic reproduction number (R_0)

The basic reproduction can be obtained by inspection in where there is only one infective class but in where there is more than one infective class, we apply the technique of (Diekman et al, 1990) which has been further studied by Van den Driessche & Watmough (2002). The reproduction number, R_0 is the average number of secondary cases an infectious person can transmit the disease to the susceptible population during his life time.

The most important threshold parameter that determines whether an infectious disease can invade a population is the basic reproduction number. If $R_0 \le 1,$

3. 5 Local stability of the endemic equilibrium

The dynamics of a disease is known by the stability at the endemic equilibrium. We will investigate the stability of the model equation at the endemic equilibrium. The endemic equilibrium is locally asymptotically stable if $R_0 > 1$.

the disease-free equilibrium is said to be locally asymptotically stable and the disease cannot invade the population. $R_0 > 1$, then the disease-free equilibrium is said to be unstable and there is possibility of the disease invading the population:

If $R_0 \le 1,$ then model (1) to (5) has a unique disease-free equilibrium.

If $R_0 > 1,$ then model (1) to (5) has a unique endemic equilibrium.

3.6 Effective reproduction number (R)

The effective reproduction number is the average number of secondary cases per infectious case in the population made up of both of susceptible and non-susceptible hosts. If R>1, the number of cases will increase, such as at the start of epidemic. Where R=1, the disease in endemic, and where R<1 there will be a decline in the number of cases.

The effective reproduction number can be estimated by the product of the basic reproductive number and the fraction of the host population that is susceptible.

$$R = R_0 X_0$$

Now, to calculate the R_0, we will consider the infected compartments which are these:

$$\frac{dI}{dt} = \beta S_u I - (\mu + \alpha) I \tag{32}$$

$$\frac{dI_T}{dt} = \theta \alpha I - (\varepsilon + \mu) I_T \tag{33}$$

We define F_i and V_i

$$F_i = \begin{pmatrix} \beta S_u I \\ 0 \\ 0 \end{pmatrix} \tag{34}$$

$$V_i = \begin{pmatrix} \mu I - (\mu + \alpha) I \\ (\varepsilon + \mu) I_T - \theta \alpha I \\ \mu I - (1 - \theta) \alpha I \end{pmatrix} \tag{35}$$

$$F = \begin{bmatrix} \frac{\partial f_1}{\partial I} & \frac{\partial f_1}{\partial I_T} \\ \frac{\partial f_2}{\partial I} & \frac{\partial f_2}{\partial I_T} \end{bmatrix} \tag{36}$$

$$F = \begin{pmatrix} \beta S_U & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \tag{37}$$

$$V = \begin{pmatrix} \mu + \alpha & 0 & 0 \\ -\theta \alpha & \mu + \varepsilon & 0 \\ -(1 - \theta) \alpha & 0 & \mu \end{pmatrix} \tag{38}$$

Inverse of matrix V

$$V^{-1} = \frac{1}{|V|}(AdjV) = \begin{pmatrix} \frac{1}{\mu+\alpha} & 0 & 0 \\ \frac{\theta\alpha}{(\mu+\alpha)(\mu+\varepsilon)} & \frac{1}{(\mu+\varepsilon)} & 0 \\ \frac{(1-\theta)\alpha}{\mu(\mu+\alpha)} & 0 & \frac{1}{\mu} \end{pmatrix} \tag{39}$$

$$FV^{-1} = \begin{pmatrix} \beta S_U & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} \frac{1}{\mu+\alpha} & 0 & 0 \\ \frac{\theta\alpha}{(\mu+\alpha)(\mu+\varepsilon)} & \frac{1}{(\mu+\varepsilon)} & 0 \\ \frac{(1-\theta)\alpha}{\mu(\mu+\alpha)} & 0 & \frac{1}{\mu} \end{pmatrix} \tag{40}$$

Recall that

$$S_u^* = \frac{\rho\Lambda_A + (\rho+\mu)\Lambda_u}{\mu^2 + (\rho+\tau)\mu} \quad \text{Where } R_0 = \tau(FV^{-1}) = \mu\beta S_U \tag{41}$$

Hence,

$$R_0 = \frac{\beta\left[\mu\Lambda_U + \rho(\Lambda_A + \Lambda_u)\right]}{\mu(\mu+\rho+\tau)(\alpha+\mu)} \tag{42}$$

Therefore, since the base reproduction number R_0 is less than 1. i.e. $R_0 \leq 1$, the disease has a unique free equilibrium state.

3.7 Numerical simulations

Under this section, we present the numerical simulation of the model; simulation of the model equation is conducted to fine out the dynamics of the disease awareness in the human population. The simulation is conducted using Maple. The initial conditions and parameter values are used and presented in Table 3.

Table 3. Data for numerical analysis

Parameter/Variable	Values	Source
$S_{A(0)}$	1500	Estimated
$S_{U(0)}$	1700	Chukwu [10]
$I(0)$	700	Chukwu [10]
$I_T(0)$	400	Chukwu [10]
$R(0)$	150	Chukwu [10]
β	0.0091	Estimated
ρ	0.05	Estimated

Parameter/Variable	Values	Source
ϕ	0.00123	Estimated
α	1.477	Chukwu [10]
θ	0.438	Estimated
μ	0.00578	Estimated
Λ_A	0.01252	Estimated
ε	0.829	Chukwu [10]
Λ_U	0.02503	Chukwu [10]
τ	0.1	Estimated

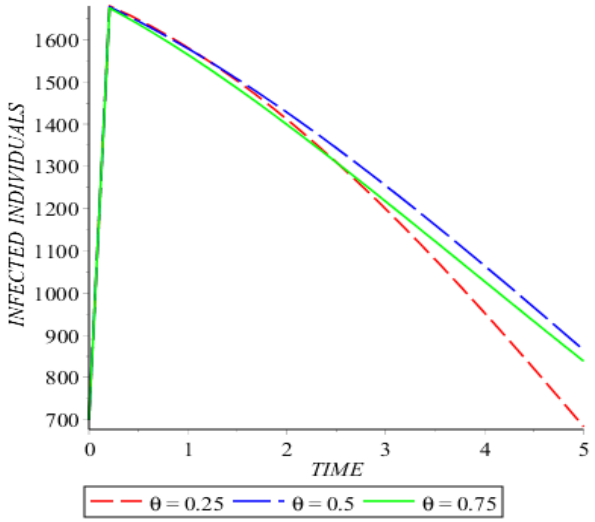

Fig. 2. The effect of the treatment rate on compartments of infected individual over time

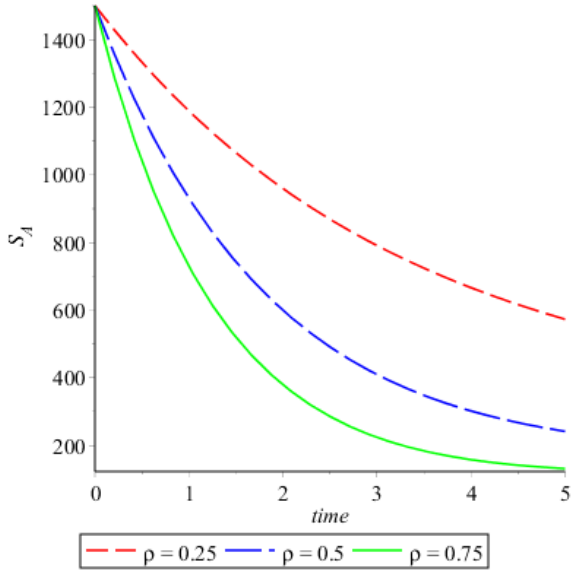

Fig. 3. The effect of non-adherence to preventive measures on the susceptible class that are aware over time

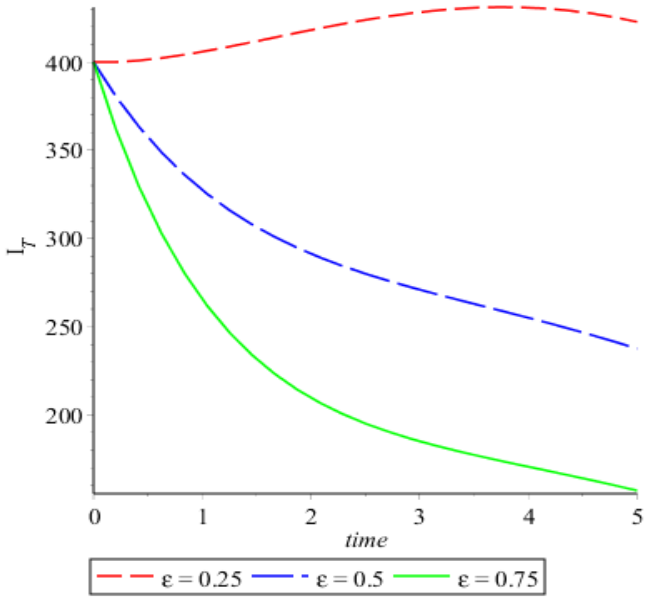

Fig. 4. The effect of adherence to preventive measures on the treated class over time

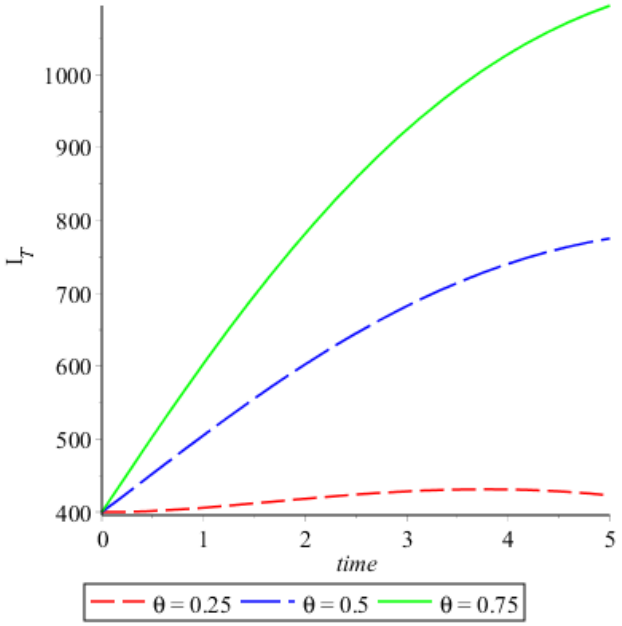

Fig. 5. The effect of the treatment rate on the treated class over time

3.8 Discussion of analytical results

From the findings of this research, there exists a disease-free equilibrium state. It was shown that if $R_0 < 1$, and then the disease-free equilibrium state is locally asymptotically stable, which implies that the disease could be eradicated under this condition in finite time. We also showed that an endemic equilibrium state exists if $R_0 > 1$, and then the endemic equilibrium is locally asymptotically stable.

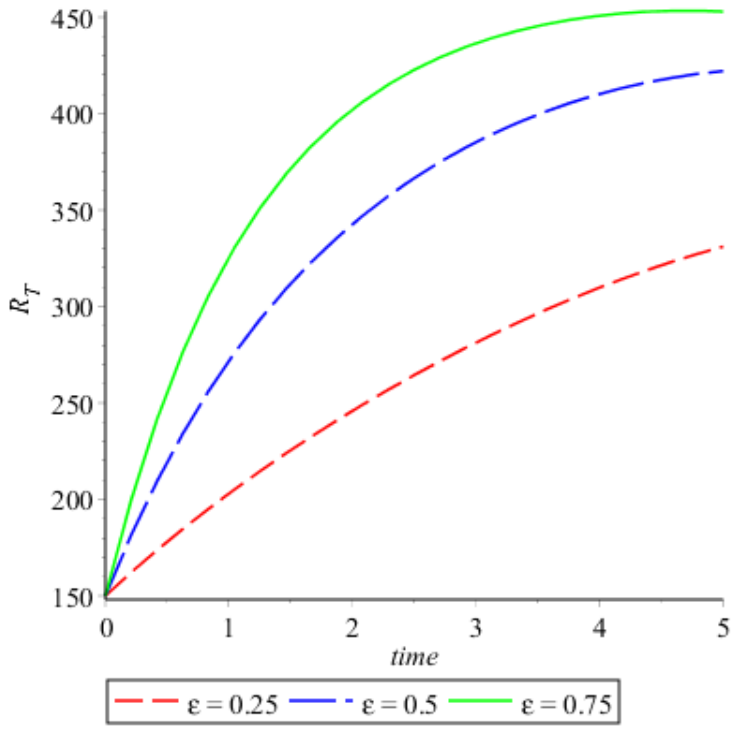

Fig. 6. The effect of the recovery rate on the treated and recover class over time

3.9 Discussion of numerical results

Fig. 2 Shows the relationship between the susceptible populations who are using both treatment compartments, and show how the infected individuals move to the treatment class.

Fig. 3 Shows the relationship between those infected with pediculosis who are undergoing treatment ρ, the result shows that there is high recovery rate as the treatment rate increases the result also shows that the treatment rate increases in the population, there is increase in the ρ population

Fig. 4 Shows the relationship between those infected with pediculosis that are undergoing treatment ε. The results prove that there is a high recovery rate from pediculesis as the treatment rate increases as the infected pediculosis population, increase in recovery rate yields a decrease in the infected population.

Fig. 5 Shows the relationship of individuals θ who moved to the treatment class on the infected population I .The result validate that with the use of awareness, there is reduction in I and show that the more individual move to treatment class, the more the infected population class.

Fig. 6 The results shows that as the rate of those who are fully recovered ε increases, the susceptible population of those that are aware also increases.

4 Conclusion

In this research, the mathematical model of pediculosis was developed using a system of first ordinary differential equation, the disease-free equilibrium state (DFE) was obtained. The effective reproduction number R_o of the model was obtained. The disease-free equilibrium was analysis for local stability. The

results showed that, the DFE is locally asymptotically stable if $R_0 < 1$. The model equation was solved analytically using Runge-kutta method. Graphical profiles were obtained from the numerical solution of the model using Maple 15. We also showed that an endemic equilibrium state exists if $R_0 > 1$, and then the endemic equilibrium is locally asymptotically stable. There is a decrease in the pediculosis infection due to awareness.

Based on our findings, we recommend that they should be more of awareness and treatment should be made available for the public especially for the rural dwellers.

1. Study should be carry out on vaccination of pedeculosis
2. Government and other immunization partner should be reinforce

Competing Interests

Authors have declared that no competing interests exist.

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