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A Mathematical Model of the Transmission Dynamics of Geohelminthes Infection in Minna, Nigeria

Paul, S.[1*], Omalu, I. C. J.[1], Bolarin, G.[2], Ejima, I. A. A.[1] and Agbo, S. S.[1]

[1] Department of Biological Sciences, [2]Department of Mathematics,
Federal University of Technology, Minna, Niger State – Nigeria
*Corresponding Author E-mail: mragbosimon82@gmail.com

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ABSTRACT

Geoheminthes infections have caused great morbidity and economic loss globally. Protecting children from this infection has become one of the principal objectives of health administrators all over the world. Development of a framework that predicts the optimal intervention level needed to effectively control this infection is indispensible. In this study, a deterministic mathematical model of the transmission dynamics of geohelminthes infection was developed, observance of hygiene and administration of medication whose effect wane over time was used to provide the framework for the model. It was observed from the simulation of the model that, when the contact rate (β) between human and parasite is 0.1, the infected class ($I(t)$) will be < 100 in 10years. Parasite density in the environment will be negligible in 20 years at an infection rate α = 0.2. while effective control of geohelminthes infection will be achieved in 5 years at a treatment rate $\gamma_1 = 0.75$ for the partially recovered and treatment rate $\gamma_2 = 0.75$ for the fully recovered person. These results are numerically verified by constructing and simulating semi analytic solutions of the model using Maple 17.

Key words: *Geoheminthes infections, Deterministic Model, Maple 17 Variation of Parameter Method (VPM).*

INTRODUCTION

Geohelminthiases are a subclass of Neglected Tropical Diseases (NTDs) that are the most prevalent in the world, particularly in the Tropical Region[16]. Globally, the estimated prevalence of geohelminthes is 15% [10]. The most prevalent parasites of the broad classification of geohelminthes are the nematodes: *Ascaris lumbricoides* (roundworm), *Trichuris trichiura* (whipworm) and the hookworm species (*Necator americanus* and *Ancylostoma duodenale*). These parasites infection causes great morbidity and severe pathological complications such as organ failure[4] which is proportionate to infection intensity. More severe complication is found in children of school age because they are the most predisposed[19].

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The infection intensity results in social, economic and educational deficit among children hence the need for effective control strategy. The current control strategy of these infections consists of preventive chemotherapy (PC) which is aimed at school age children and pre-school children[20]. Although this control strategy is effective in reducing the infection burden in children, it does not prevent rapid re-infection[1,6,11]. As such, treatment must be administered regularly at intervals to maintain a lasting effect of medication which only offers temporary immunity to these infections. Thus, a much better approach is the design of a framework that guides periodic chemotherapeutic interventions, in terms of who to treat, at what level of coverage and how often to get the biggest impact on parasite transmission and disease burden or in achieving elimination. Mathematical models are a significant tool in understanding the transmission of geohelminthes infection and the impact of interventions[18]. It has been used to provide deeper insights into the transmission dynamics of several childhood diseases and to evaluate control strategies[8,12,18]. Mathematical models of deterministic type also inform policy making, and in particular the feasibility of achieving the less than 1% prevalence of moderate and heavy intensity infection of soil transmitted helminthes by 2020 [20]. Ideally, this model is based on data obtained from the field and contains simplified model of school age children with the aim of determining the intervention coverage period needed for effective control of soil transmitted helminthes.

MATERIALS AND METHODS

Methods

Model variables and parameters were obtained by parasitological survey and simulations were generated with the aid of maple 17 VPM solver using the parameter values as shown on table 1.

The modified model for infectious diseases which incorporates a preventive medication which effect wane over time was studied. The aim is to use this model to predict the optimal intervention coverage and time needed to ensure that the infection is effectively controlled or eliminated. The model monitors the dynamics of:

a. geohelminthes in the environment (W),
b. the susceptible individuals from age 6 – 16 years (S);
c. infected individuals from age 6 – 16 years (I),
d. partly recovered individuals from age 6 – 16 years (Q),
e. fully recovered individuals from age 6 – 16 years (R)

The model consists of the following equations:

$$\frac{ds}{dt} = \wedge - \mu S - \beta S\left(\frac{W}{K+W}\right) + \rho R \text{ --------------------- } 3.1$$

$$\frac{dI}{dt} = \beta S\left(\frac{W}{K+W}\right) - I\,(\mu + \alpha + \gamma 1 + \gamma 2) \text{ ----------------- } 3.2$$

$$\frac{dQ}{dt} = \gamma 1 - Q\,(\mu + \delta) \text{ ---------------------------- } 3.3$$

$$\frac{dR}{dt} = \gamma 2 + \delta Q - R\,(\mu + \rho) \text{ ------------------------- } 3.4$$

$$\frac{dW}{dt} = AI - W\,(\mu 1 + \mu 2) \text{ -------------------------- } 3.5$$

Where β is the effective contact rate, $\wedge$ is the constant recruitment rate into the population either by birth or immigration, $\mu + \delta$ is the total death rate of human, γ is the recovery rate from geohelminthes infection after treatment, $\delta + \mu$ is the death rate of human due to geohelminthes, ρ is the waning rate of temporary immunity μ_1 is the helminthes reproduction rate, μ_2 is the helminthes death rate, σ is the rate of partial recovery from geohelminthes, γ is the rate of full recovery from infection, γ_1 is the rate of partial recovery from geohelminthes infection.

The variables/parameter values used in simulations are given in Table 1. All variables were obtained from the field survey. It contains dimensional and non-dimensional model parameters with default values used in all calculations (unless otherwise stated).

RESULTS

From simulation, an effective contact (β) = 0.1 brings the population of infected individuals to 0 in less than 16 years, (fig 1) while a treatment rate of γ_1 = 0.75 will bring the population of infected persons (I) to zero in 5 years (figure 2). The population of those who are partially recovered (Q) will be significantly reduced at treatment rate γ_1 = 0.25, in 10 years (fig 4) while in 5 years, the population of partially recovered individuals (Q) will be zero at treatment rate γ_2 = 0.75 (fig 4). At γ_2 = 0.75 effective control will be achieved in 20 years as the population of the recovered (R) would have been in the climax (fig 5) and the worm density in the environment will be significantly low in 15 years at infection rate α = 0.20 (fig 6).

Table 1: Model operational parameters

Variables	Definition	Values	References
S	Susceptible individuals in study population	545	From the study
I	Infected individuals in study population	225	From the study
R	Recovered individuals in study population	176	From the study
Q	Partially recovered individuals in study population.	225	From the study
W	Worm burden		
Parameters			
$\wedge$	Constant recruitment rate	1/18,250 day^{-1}	Norman *et al.*, 2000
Β	Effective contact rate	0.8	
	Total death rate of human	1/18,250 day^{-1}	Norman *et al.*, 2000
Γ	Recovery rate from helminthes	1/7 days^{-1}	Norman *et al.*, 2000
$\delta + \mu$	Death rate of humans due to helminthes	35/1000 persons	Peter *et al.*, 2017
Ρ	waning rate of temporary immunity	1/7 days $^{-1}$	Norman *et al.*, 2000
μ_1	Helminthes reproduction rate	1/15 days^{-1}	Norman *et al.*, 2000
μ_2	Helminthes death rate	13/37500 day^{-1}	Norman *et al.*, 2000
Σ	Rate of recovery from partial recovery	1/7 days^{-1}	Norman *et al.*, 2000
γ_2	Rate of full recovery from infection	1/7 days^{-1}	Norman *et al.*, 2000
γ_1	Rate of partial recovery from infection.	1/7 days^{-1}	Norman *et al.*, 2000
Α	Rate of infection	0.2	Norman *et al.*, 2000
$\delta + \mu$	Death due to intestinal helminthes annually	150,000 death	Crompton 1999

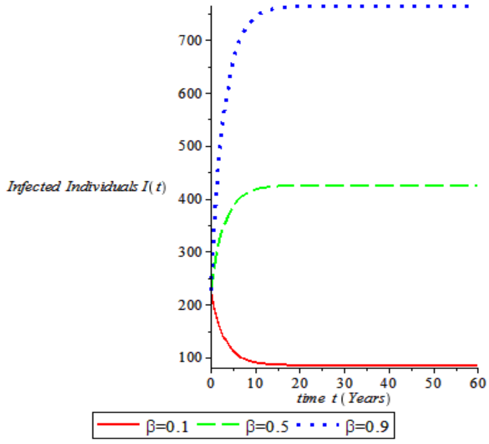

Fig. 1: Graph of population of infected (*I*) against time (t) at low, moderate and high contact rate (β)

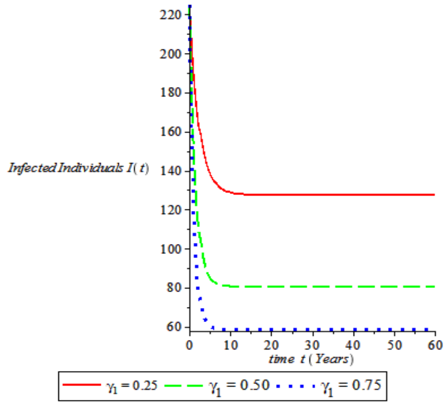

Fig. 2: Graph of population of infected (*I*) against time (t) at low, moderate and high treatment rate (γ_1)

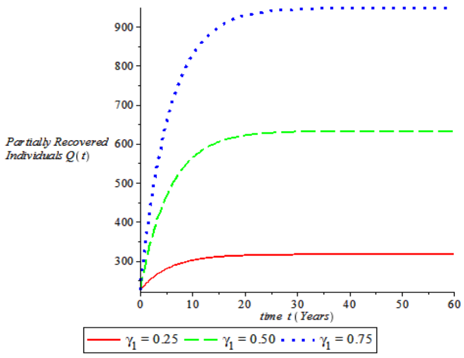

Fig. 3: Graph of population of the partially recovered (*Q*) against time (t) at low, moderate and high treatment rate (γ_1)

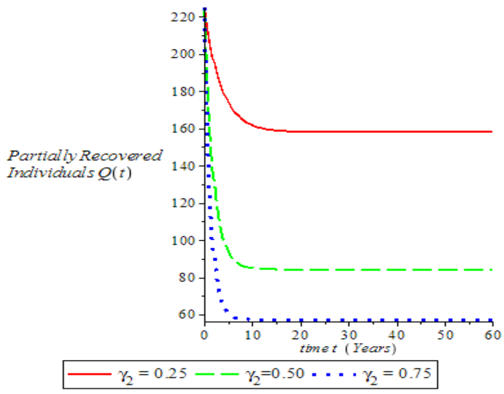

Fig. 4: Graph of population of the partially recovered (*Q*) against time (t) at low, moderate and high treatment rate (γ_2)

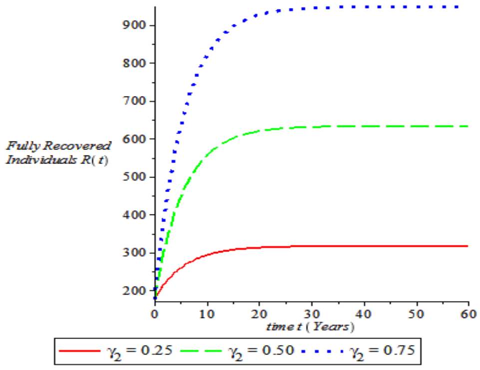

Fig. 5: Graph of population of the fully recovered (*R*) against time (t) at low, moderate and high treatment rate (γ_2)

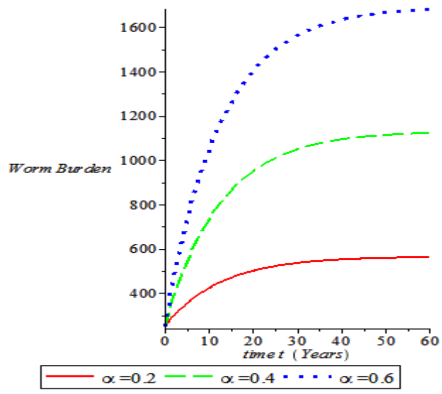

Fig. 6: Graph of worm density in environment (*W*) against time (t) at low, moderate and high infection rate (α)

DISCUSSION

In this study of a deterministic model of the transmission dynamics of geohelminthes among school age children, immunity conferred by medication is assumed to wane within a short time, that not all those who got medication were fully recovered and the period within which intervention is sufficient to effectively control geohelminthes were studied. Result revealed that the effective contact rate (β), is indirectly proportionate to the population of infected persons (I). This means that if adherence to the observance of risks factors and control measures is sustained, in about twelve years, geohelminthes prevalence will be significantly reduced to 0%. For example, a study on *closteredium deficile* revealed that enhancing environmental decontamination can reduce its incidence by 38–85% [3]. Also, a study by [5] on the model predictions of the effectiveness of observance of risks factors revealed a 43% reduction in prevalence and had hygiene and sanitation 49% reduction[23].

It also showed that as treatment rate increases, population of those infected reduced and when a treatment rate of $\gamma_1 = 0.75$ is sustained for five years will eradicate geohelminthes infection. In a study were co-infection of Malaria and Lymphatic Filariasis were modeled, the result demonstrated that treatment rate reduces the burden of filarial worm significantly but re-infection was a problem since treatment was not sustained[19]. It also showed that in the case of improper treatment, the number of the partially recovered rose disproportionately[7,10]. The result also revealed that treatment rate is proportionate to the rate of full recovery and that if treatment is sustained at high rates full recovery will reach the climax in twenty years and geohelminthes infection will be at its lowest point.

The result also revealed that treatment rate is proportionate to the rate of full recovery and the model predicts that if treatment is sustained at high rate, full recovery of infected population will reach the climax in twenty years and geohelminthes infection will be at its lowest point. Similarly[24] reported a significant increase of 15 – 84% in recovery rate after treatment while in a study on control of outbreak of infection reported an increase in recovery of 31 – 71% [15]. It is also evident from the result that infection rate increases as the population of worm in the environment increases and the increase will be continuous.

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