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Transmission dynamics of schistosomiasis in Zimbabwe: A mathematical and GIS Approach

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ABSTRACT

Temperature and presence of water bodies are known to influence the transmission dynamics of schistosomiasis. In this work, effects of water bodies (taken in context of rainfall patterns) and temperature from 1950 to 2000 are considered in the model. With the aid of Geographic Information System (GIS), the reproduction number is mapped on the Zimbabwean country. Results of the mapping show high reproduction numbers along the Lowveld and the Zambezi valley catchment area. High reproduction numbers suggest high levels of schistosomiasis. This result suggests more control efforts should be targeted in these areas with high reproduction numbers.

1. Introduction

Schistosomiasis also referred to as bilharzias (or snail fever) is an infectious disease caused by parasitic flatworms of the genus schistosoma. It is a major source of morbidity affecting over 250 million people worldwide, with 85% occurring in the developing tropical countries in Africa, Asia, South America and the Middle East [1,2]. In terms of morbidity and mortality, schistosomiasis is considered the second most important human parasitic disease after malaria [3]. Schistosomiasis continues to drain the socio-economic development of already impoverished rural communities of sub-Saharan Africa.

Schistosomiasis may localise in different parts of the body and its localisation determines its particular clinical profile [4]. Schistosomiasis is caused by five species of flatworms, each of which causes a different clinical presentation of the disease. Intestinal schistosomiasis is caused by Schistosoma mansoni, urinary schistosomiasis is caused by Schistosoma haematobium and Schistosoma japonicum and Schistosoma mekongi cause Asian intestinal schistosomiasis [5]. Three species of schistosomiasis, S. haematobium (prevalent in Africa), S. japonicum (prevalent in Japan, Southeast Asia, and Western Pacific) and S. mansoni (prevalent in Africa, Southwest Asia, Brazil and the Caribbean) are responsible for the majority of schistosomiasis infection while the other two species, S. intercalatum and S. mekongi parasitise humans to a much lesser extent [6]. Flatworms infect humans by penetrating the skin when exposed to contaminated freshwater (e.g., when wading, swimming, or bathing). The flatworms spread in freshwater areas, such as rivers and lakes, where freshwater snails act as intermediate hosts for the parasite's larvae. As such, the habitats of the host snails are of great importance for the spread of the disease. The most important determinants of the population dynamics of snails are temperature and rainfall [4]. The best survival temperature of snails was found to be between 20 °C and 25 °C while at 40 °C none of the snails survived [8]. However, snails are less sensitive to low temperatures

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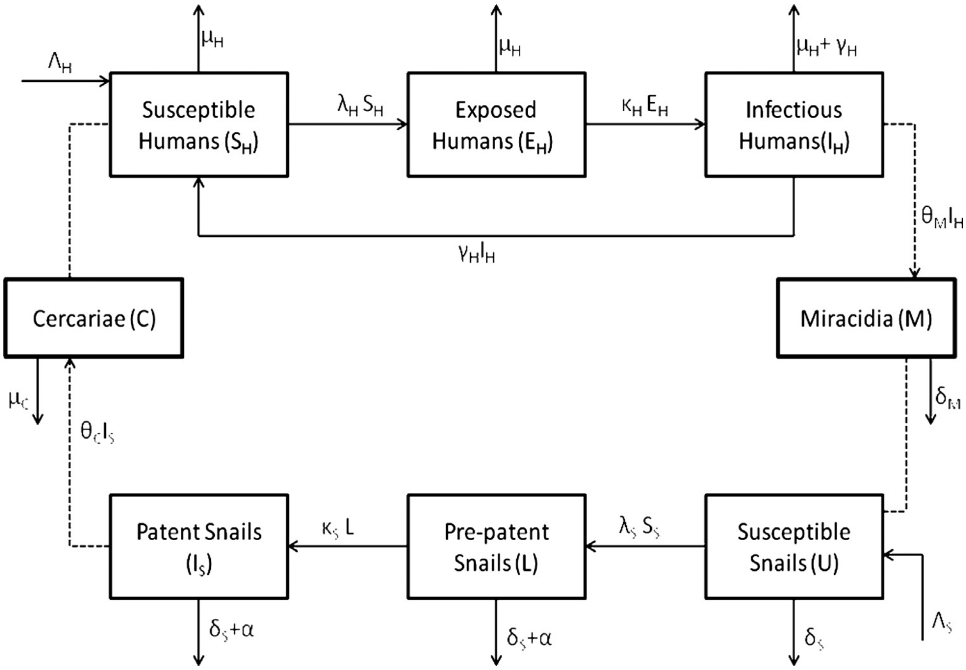

Fig. 1. Model diagram of the mathematical model for schistosomiasis transmission. Dotted lines on the diagram denote indirect interaction.

than schistosome parasites in snails. Uninfected snails can therefore be found in high altitude areas of endemic countries where low temperatures inhibit larval development in snails [7]. Dagal et al. [8] considered the effects of water temperatures on hatchability of eggs and survival of snails and found that at low temperatures 15 °C, none of the eggs hatched. The mean survival rate of snails between 5 °C and 10 °C was found to be zero. As temperature increased, hatching rate increased but at 35 °C none of the eggs hatched.

Incorporating climate effects into models of disease dynamics is now extremely important as there is a strong need to understand the effects of climate change. The schistosome and snail life cycles are highly dependant on ambient conditions and climate change is known to affect several parameters in the epidemiology of schistosomiasis. Developing an epidemiological model to predict how these factors bring out the impact of climate on the dynamics of schistosomiasis transmission is crucial. Here, a schistosomiasis model is incorporated into geographic information systems (GIS) to get a feel of the possible variation of schistosomiasis intensity in Zimbabwe.

2. Model formulation

The life cycle of schistosome parasites is complicated and involves two different hosts: human beings and snails. A model to trace the life cycle of schistosome parasite is formulated. The model is based on monitoring the dynamics of the populations at any time t of susceptible humans $S_H(t)$, exposed humans $E_H(t)$, infectious humans I_H, miracidia $M(t)$ (larvae of the parasite soon after hatching from the eggs), uninfected snails $U(t)$, latently infected snails $L(t)$, patent infected snails (infected snails not yet releasing cercariae) $I_s(t)$ and cercariae $C(t)$ (larvae released into the water from infected snail ready to enter the human skin). Individuals are recruited into the human population at a rate Λ_H. Susceptible individuals acquire infection at a rate $\lambda_H = \frac{\beta_H C(t)}{C_0+\epsilon C(t)}$, where β_H is the cercarial infection rate, C_0 is a saturation constant for the cercariae and ϵ is the limitation of the growth velocity of cercariae with the increase of cases. Upon infection, an individual does not automatically become infectious but enters an exposed class as the incubation period of schistosomiasis ranges from 4 to 8 weeks for schistosomiasis mansoni and schistosomiasis japonicum, respectively [9,10]. Individuals then progress to the infectious compartment at a rate κ_H. Susceptible and infected individuals suffer from natural death rate μ_H, but infectious individuals have an additional host mortality δ_H. Adult schistosomes within infected human hosts produce eggs which hatch and develop to free-swimming miracidia at a net rate θ_M. Miracidia either die at a rate δ_M or infect uninfected snails at rate $\lambda_S = \frac{\beta_S M}{M_0+\epsilon M}$. Adult snails are recruited into the susceptible snail population at a rate Λ_S. Upon infection, snails enter the latently infected class from which they progress to the patent infected class at a rate κ_S. Adult snails die naturally at rate δ_S and infected adult snails also die due to parasite-induced mortality at an additional rate α. The patent infected snails will then release a second form of free swimming larvae called cercariae at a rate θ_C which is capable of infecting humans. Cercariae die naturally at the rate δ_C.

A compartmental model of schistosomiasis dynamics is presented in Fig. 1.