Using NOAA-AVHRR Data to Model Human Helminth Distributions in Planning Disease Control in Cameroon, West Africa

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Abstract

Human helminth infections (intestinal nematode infections such as Ascaris lumbricoides, Trichuris trichiura, *and hookworm, and schistosome infections such as* Schistosoma haematobium *and* S. mansoni*) affect more than a quarter of the world's population, with potential consequences for the health and nutritional and educational development of infected individuals. The advent of broad-spectrum anthelminthic drugs that are cheap, safe, and simple to deliver has meant that control has become a viable option for many countries. Because helminth infections patterns are highly heterogeneous, methods to identify priority areas for intervention against intestinal nematode and schistosome will enhance the efficacy of control. This paper describes the use of NOAA-AVHRR data to develop logistic regression models that predict the probability of infection prevalence greater than 50 percent, and thus warrant mass treatment for intestinal nematodes and schistosomes, according to WHO's criteria. Moreover, by overlaying the resulting risk maps on population surfaces, it is possible to estimate the school-aged population size requiring mass treatment and also provide an estimate of program costs.*

Introduction

More than fifty years ago, a seminal paper entitled "This Wormy World" (Stoll, 1947) showed that helminth infections, including schistosome and intestinal nematode species, were among the most common of human infections. Today, these infections still affect more than a quarter of the world's population (Chan *et al.*, 1994; Bundy, 1997), with potential consequences for children's physical and intellectual development (Stephenson, 1987; Watkins and Pollitt, 1997).

The advent of broad-spectrum anthelminthic drugs that are cheap, safe, and simple to deliver has meant helminth control has become a viable option for many countries. The World Health Organization (WHO) presently recommends mass anthelminthic treatment in areas where infection prevalence (proportion of community infected) is 50 percent or greater (WHO, 1995a). Praziquantel is used to treat the schistosomes (*Schistosoma haematobium* and *S. mansoni*), and intestinal nematodes (*Ascaris lumbricoides*, *Trichuris trichiura*, hookworm) are treated by the benzimidazole drugs, albendazole and mebendazole (WHO, 1995b). Studies have shown that these treatments can be safely and effectively combined (Savioli *et al.*, 1997; Olds *et al.*, 1999), and the WHO recommends joint delivery in areas where both groups of parasites occur (WHO, 1995a). It has been suggested that the overlap in the geographical distribution of each group of species is sufficiently large to justify combined treatment (Bundy *et al.*, 1991), but more detailed analysis suggests uneven and often non-overlapping distributions within countries (Brooker *et al.*, 1999). This indicates a more refined approach to combined control is required, whereby target communities are identified separately for intervention against schistosomes and intestinal nematodes, and drugs are distributed according to local needs, thus reducing delivery costs and the prospect of drug resistance.

In an effort to better understand the distribution of species, geographic information systems (GIS) are increasingly being used to collate and map available helminth survey data available from the formal and "grey" literature (Brooker *et al.*, 2000a). Such information on the distribution of infection will be central to successfully addressing the key operational questions of reliably estimating the target population numbers at risk (Brooker *et al.*, 2000b), stratifying areas by prevalence to prioritize areas for control, and estimating overall drug needs and costs. Although there is comprehensive information on helminth distributions in some African countries, empirical survey data are available for only a third of administrative districts across the continent (Brooker *et al.*, 2000a).

To help fill the gap in empirical data, remotely sensed (RS) satellite sensor data and interpolated meteorological surfaces are being used to predict the distributions of a variety of infectious diseases (Malone *et al.*, 1997; Hay *et al.*, 2000; Rogers, 2000; Lindsay and Thomas, 2000; Malone *et al.*, 2001). For helminth species, years of field studies have documented the influence of climate and environmental variables on the distribution of helminth infections (Appleton, 1978; Brown, 1994; Crompton, 1994), and RS-derived environmental variables and meteorological variables are of potential use in predicting the occurrence of significant transmission (Brooker and Michael, 2000). The present study uses environmental data derived from meteorological satellite sensors and interpolated meteoro-

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logical data to model the distribution of schistosome and intestinal nematode infections in Cameroon. These distributions are then used to quantify the population requiring treatment and to estimate the financial costs of school-based programs using single species or combined control options.

Methods

Epidemiological Data

Prevalence data were collected during a nation-wide survey of helminth infection in 1985–1987 originally aggregated at the district level (Ratard *et al.*, 1990; Ratard *et al.*, 1991). These data are stratified at the school level here because schoolchildren are the primary targets for treatment and the educational infrastructure is usually used to deliver treatment. The original study was designed to provide data on the nationwide distribution of helminth infections using a stratified, random-cluster sampling procedure with the primary school as the basic sampling unit. In the north of the country where school enrollment was low, all children from the appropriate age group living in the community were invited to participate (Ratard *et al.*, 1990). Urine and stool samples were examined by sedimentation and the Kato-Katz thick smear technique, respectively. The location of schools was obtained by transcribing coordinates from 1:25,000-scale maps used in the original survey. Data on intestinal nematode species (*Ascaris lumbricoides* and *Trichuris trichiura*) for 18,260 school children aged 10 to 19 years in 402 schools and data on schistosome species (*Schistosoma haematobium*) for 19,524 children in 303 schools were collected.

Satellite Sensor Data

Land Surface Temperature (LST) and the **n**ormalized **d**ifference **v**egetation **i**ndex (NDVI) information were derived from the Advanced Very High Resolution Radiometer (AVHRR) on board the National Oceanic and Atmospheric Administration's (NOAA) polar-orbiting meteorological satellites (Cracknell, 1997) using Price (1984) and Tucker (1979) procedures, respectively. Daily data at 8- by 8-km spatial resolution were first processed for the period 1985 through 1998 to exclude unreliable pixels due to extreme sun and sensor viewing angles and cloud contamination (see Hay and Lennon, 1999). Single monthly images were then maximum-value composited (Holben, 1986). Minimum, mean, and maximum values of these data were extracted for each pixel that corresponded to the location of the parasitological surveys. Image processing was performed using the Earth Resources Data Analysis System (ERDAS) Imagine 8.4™ (ERDAS, Inc., Atlanta, Georgia).

Other Environmental Data

Interpolated rainfall surfaces were taken from the Spatial Characterization Tool (Corbett and O'Brien, 1997), and an interpolated digital elevation model (DEM) of Africa was obtained from the Global Land Information System (GLIS) of the United States Geological Survey (EROS Data Center, 1996).

Population Data

District population data were derived from a 1990 national population forecast based on the 1987 national census (Deichmann, 1996), and were projected to 2001 using annual specific growth rates obtained from the United States Census Bureau (2001).

Statistical Analysis

To examine the relationship between environmental variables and the need for mass treatment, schools were classified as having prevalence above or below 50 percent, WHO's treatment threshold (WHO recommends that mass treatment is warranted if the prevalence in a school exceeds 50 percent infection). Logistic regression models were developed to identify significant environmental variables affecting the transmission of infection. A potential problem in developing regression models using environmental vari-ables is that many are highly intercorrelated so that it is difficult to separate the effects of the independent variables statistically (Morgenstern, 1998). To reduce the dimensionality of these collinear variables, we first selected those variables likely to have greater biological significance on infection transmission (Brooker and Michael, 2000). Second, the remaining variables were added to the models in a stepwise fashion, and the statistical fits of alternative models were compared using the residual deviance of models including and excluding correlated variables using a χ^2 distribution (Venables and Ripley, 1999). Analysis was done using S-Plus 4.5 Professional Release 2 (Math Soft, Seattle, Washington).

The best-fit logistic regression models were then used to map the probability of infection prevalence being greater than 50 percent using Idrisi Version 2 (The Idrisi Project, Worcester, Massachusetts). To define whether a district would be a priority area for control, we have used an arbitrary criteria based on whether the average logistic regression probability is greater than 0.5 within a district. On this basis, the number of school-aged children who would receive mass treatment for intestinal nematodes was estimated. The population size for praziquantel and albendazole treatment was calculated by overlaying the predictive maps of infection prevalence on a population map. For albendazole we used a combined estimate of infection prediction for either *A. lumbricoides* or *T. trichiura*.

Cost Data

Detailed prospective cost analyses have been conducted for school-based anthelmintic programs in Ghana and Tanzania (Partnership for Child Development, 1999a). The cost of mass distribution of a single dose of albendazole for intestinal nematodes to schoolchildren by their teachers was US$0.03 in both countries. The cost of delivering praziquantel for schistosomes—which required targeting schools by a questionnaire, and required a calculation to determine the dose based on the height of the child—was US$0.67 in Ghana and US$0.21 in Tanzania. The figures for Tanzania and Ghana were used to estimate the lower and upper costs of implementing a school-based helminth control program in Cameroon.

Results

Logistic Regression Models

A number of different logistic regression models were fit to the data, and residual deviances were compared to identify the best-fit models. The variables available to the regression analysis were mean, minimum, and maximum LST and NDVI; total annual rainfall; and altitude. Studies show that maximum temperature is an important variable in determining helminth distribution because of the effect of heat and low humidity on the embryonation, development, and survival of free-living infective stages and intermediate hosts (Brooker and Michael, 2000). Consequently, this variable was entered into the regression model first; next, minimum and mean LST were included and the additional model improvement was assessed. Added next to the model analysis was NDVI (minimum, maximum, and mean), rainfall, and altitude. The derived species-specific models (Table 1) indicate (1) the importance of maximum LST, (2) the influence of rainfall, and (3) the influence of NDVI.

The results for *A. lumbricoides* and *T. trichiura* indicate a negative effect of maximum LST. For helminth species, temperature is a density-independent factor effecting parasite transmission, as measured by the basic reproductive number (R_0) (Anderson and May, 1991; Brooker and Michael, 2000), and thus observed patterns of infection prevalence. As temperature increases, transmission and infection prevalence decrease.

Table 1. Regression Coefficients Describing the Logistic Regression Models. LST = Land Surface Temperature; NDVI = Normalized Difference Vegetation Index

	B	Residual deviance	P (<)
S. haematobium			
Constant	−228.16	58.1	
Maximum LST	0.14	32.6	0.001
Rainfall	0.02	21.3	0.001
A. lumbricoides			
Constant	75.31	549.4	
Maximum LST	−0.05	294.5	0.001
Maximum NDVI	0.04	286.6	0.004
Rainfall	−0.002	256.1	0.001
T. trichiura			
Constant	142.4	525.9	
Maximum LST	−0.003	181.3	0.001
Mean LST	−0.17	155.5	0.001

In contrast to the models for *A. lumbricoides* and *T. trichiura*, maximum LST has a positive effect on *S. haematobium*. In Cameroon, the predominant snail species are *Bulinus senegalensis* in the north of the country and *Bu. globosus* and *Bu. truncatus* in the south (Wright, 1959; Greer *et al.*, 1990). The former is found principally in semi-permanent water bodies and can survive the dry season by aestivation. By contrast, the two southern species tend to occur in more permanent water bodies. These features of snail distributions suggest that the model for *S. haematobium* is in fact predicting the distribution of *Bu. Senegalensis*. Specifically, the model is predicting habitats suitable for this species, i.e., areas with semi-permanent water bodies which arose from periodic drying out due to high temperatures. Moreover, the rarity of water points in the north leads to a concentration of human water contacts with fewer water points available, thus increasing the risk of transmission. In the south, by contrast, human water contacts are more dispersed among numerous water bodies, decreasing the risk of transmission.

Estimates of Treatment Population Size and Program Costs

The best-fit regression models were then used to generate probability maps of infection prevalence greater than 50 percent for *S. haematobium*, *A. lumbricoides*, and *T. trichiura* (Figure 1). These maps indicate that different areas would warrant mass treatment with albendazole than those requiring mass treatment with praziquantel—combined control would not be justified in most areas.

We estimate that 5.8 million school-aged children in 33 of 49 districts in Cameroon would warrant mass treatment with albendazole. Using the model for *S. haematobium*, we estimate no districts would warrant mass treatment at the 50 percent threshold. However, because there will be heterogeneity of prevalence within districts and there should be flexibility in the treatment thresholds to suit local needs, the analysis was re-run using a 20 percent prevalence threshold. On this basis, we estimate that 1.8 million school-aged children in nine districts would receive mass treatment with praziquantel. For *S. haematobium*, an effective approach to help locate high-risk communities/schools requiring mass treatment within at-risk areas has been the use of blood in urine questionnaires (Red Urine Group, 1995; Partnership for Child Development, 1999b). To identify priority areas for questionnaire surveys, the present broad-scale ecological predictions can provide relevant information.

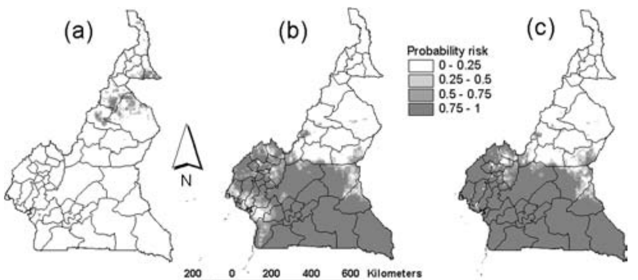

Figure 1. Predicted probability of having infection prevalence greater than 50 percent. (a) *S. haematobium*. (b) *A. lumbricoides*. (c) *T. trichiura*.

Estimates of treatment costs were developed based on the predicted target population size. Using the Tanzania cost data as a lower estimate and the Ghana cost data as an upper estimate, we suggest that the cost of control for *A. lumbricoides* and *T. trichiura* (using albendazole) would be US$ 0.18 million and for *S. haematobium* (using praziquantel) would be US$ 0.39 to 1.24 million.

Discussion and Conclusions

These results indicate that RS and meteorological data offer the opportunity to investigate the distribution of intestinal nematode and schistosome infection and some of the ecological factors that limit transmission, for purposes of predicting infection distributions. This will prove valuable for health planners in the majority of low-income countries where there is a lack of detailed empirical survey data. Equally important for national health planning, the results will help provide estimates of control program costs of delivering anthelmintics through the school system. This has important implications for the efficient allocation of scarce health resources.

Previously, the sensitivity of helminth transmission to climate variation, and the use of models using NOAA-AVHRR data to predict infection patterns, have been described for *S. mansoni* (Malone *et al.*, 1994; Malone *et al.*, 2001). In Egypt, Malone *et al.* (1994) used 1-km resolution data to derive maps of diurnal temperature differences (dT), which indicate surface and sub-surface moisture contained in soil and plant canopy and hence may act as a surrogate for the abundance of the snail vector, *Biomphalaria alexandrina*, whereby wetter and more suitable habitats for *Bi. alexandrina* corresponded to lower dT values. They found that low values of dT are associated with increased snail abundance in wet areas with a slow current flow, and is closely mirrored in the patterns of *S. mansoni* prevalence. Malone *et al.* (2001) also used 1-km AVHRR data to produce maps of LST and NDVI to study the distribution of *S. mansoni* in Ethiopia. They found that annual composite maximum LST values of 20 to 33°C and wet season values of 18 to 29°C defined the distribution of *S. mansoni* prevalence greater than 5 percent in Ethiopia, and used these limits to predict infection risk within the country. In an analysis of survey data from Tanzania (Brooker *et al.*, 2001), we have used 8-km AVHRR to develop predictive models of *S. haematobium*. We found that the model allows reasonable discrimination between high- and low-prevalence schools, at least within those geographical areas in which they were originally developed, and performs reasonably well in other coastal areas, but performs poorly in comparison in the Great Lakes area of Tanzania. Despite these applications for *S. mansoni* and *S. haematobium*, we believe that there are no published studies using satellite sensor data to predict distributions of intestinal nematodes in Africa.

Although the present analysis uses the example of Cameroon because of the geographically detailed data available for the country, the approach can be extended to other countries in Africa. The potential of such an approach will, however, remain undefined until further studies are undertaken which consider several issues. The first issue relates to the problem of spatial scale (Wiens, 1989; Levin, 1992; Walsh *et al.*, 1999). The problem is that many biological responses are scale-dependent (Wiens, 1989), and observed associations between disease transmission and environmental variables vary as the scale changes. In the context of helminth control, the rationale for prediction is to provide information on the spatial patterns of infection and disease at the administrative level at which control resources are likely to be mobilized, usually the district level. Furthermore, although RS data are available at fine spatial scales, the satellite systems most widely used in the RS community are those with a broad spatial scale of 1 to 8 km. We used AVHRR 8-km satellite sensor data to model the probability of areas having infection of 50 percent or greater and warranting mass treatment with anthelmintics. Other studies conducted at different scales may reach different conclusions (Walsh *et al.*, 1999).

A further issue is that different environmental variables may impact upon helminth transmission in different areas (Appleton and Gouws, 1996; Brooker and Michael, 2000) and, in the case of schistosomiasis, different snail species may be differently affected by environmental variability responsible for disease transmission (Malone *et al.*, 2001; Brooker *et al.*, 2002). The development of separate or modified models of spatial distribution of infection will provide the basis for a wider and more detailed analysis of the population size at risk of infection and allow for the more targeted and rational implementation of control programs in Africa. The challenge lies however in defining the spatial envelope in which developed models can be applied and where different models are required. This is an area of ongoing research.

In summary, the models developed here provide health planners with a means of predicting the geographical distribution of intestinal nematodes and schistosomes for the purposes of targeting control and for estimating likely program costs. With the development of further models, the approach could provide, for the whole of Africa, reasonable predictions of the need to mass treat with albendazole and praziquantel, and identify areas where a single or combined control approach is warranted. This will provide a potentially valuable planning tool for planning and implementing control programs aimed at reducing the disease burden due to helminth infections among African school children.

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