Use of remote sensing and a geographical information system in a national helminth control programme in Chad

Simon Brooker,[1] Michael Beasley,[2] Montanan Ndinaromtan,[3] Ester Mobele Madjiouroum,[4] Marie Baboguel,[5] Elie Djenguinabe,[6] Simon I. Hay,[7] & Don A.P. Bundy[8]

Objective To design and implement a rapid and valid epidemiological assessment of helminths among schoolchildren in Chad using ecological zones defined by remote sensing satellite sensor data and to investigate the environmental limits of helminth distribution.

Methods Remote sensing proxy environmental data were used to define seven ecological zones in Chad. These were combined with population data in a geographical information system (GIS) in order to define a sampling protocol. On this basis, 20 schools were surveyed. Multilevel analysis, by means of generalized estimating equations to account for clustering at the school level, was used to investigate the relationship between infection patterns and key environmental variables.

Findings In a sample of 1023 schoolchildren, 22.5% were infected with *Schistosoma haematobium* and 32.7% with hookworm. None were infected with *Ascaris lumbricoides* or *Trichuris trichiura*. The prevalence of *S. haematobium* and hookworm showed marked geographical heterogeneity and the observed patterns showed a close association with the defined ecological zones and significant relationships with environmental variables. These results contribute towards defining the thermal limits of geohelminth species. Predictions of infection prevalence were made for each school surveyed with the aid of models previously developed for Cameroon. These models correctly predicted that *A. lumbricoides* and *T. trichiura* would not occur in Chad but the predictions for *S. haematobium* were less reliable at the school level.

Conclusion GIS and remote sensing can play an important part in the rapid planning of helminth control programmes where little information on disease burden is available. Remote sensing prediction models can indicate patterns of geohelminth infection but can only identify potential areas of high risk for *S. haematobium*.

Keywords Helminths/growth and development; Helminthiasis/epidemiology; Schistosoma haematobium/growth and development; Schistosomiasis haematobia/epidemiology; Ancylostomatoidea/growth and development; Hookworm infections/epidemiology; Ascaris lumbricoides/growth and development; Trichuris/growth and development; Environmental monitoring; Ecology; Information systems; Epidemiologic studies; Chad (*source: MeSH, NLM*).

Mots clés Helminthe/croissance et développement; Helminthiases/épidémiologie; Schistosoma haematobium/croissance et développement; Schistosomiase urinaire/épidémiologie; Ancylostomide/croissance et développement; Ankylostomiase/épidémiologie; Ascaris lumbricoides/croissance et développement; Trichuris/croissance et développement; Surveillance environnement; Ecologie; Système information; Etude analytique (Epidémiologie); Tchad (*source: MeSH, INSERM*).

Palabras clave Helmintos/crecimiento y desarrollo; Helmintiasis/epidemiología; Schistosoma haematobium/crecimiento y desarrollo; Esquistosomiasis haematobia/epidemiología; Ancylostomatoidea/crecimiento y desarrollo; Infecciones por uncinaria/epidemiología; Ascaris lumbricoides/crecimiento y desarrollo; Trichuris/crecimiento y desarrollo; Monitoreo del ambiente; Ecología; Sistemas de información; Estudios epidemiológicos; Chad (*fuente: DeCS, BIREME*).

Bulletin of the World Health Organization 2002;80:783-789.

Voir page 788 le résumé en français. En la página 788 figura un resumen en español.

Introduction

A geographical information system (GIS) is a computerized system that combines spatial and descriptive data for mapping and analysis (*1*). One of the main strengths of a GIS is its ability to integrate different types of spatial data. For example, a GIS can be used to map available epidemiological information and relate it to factors known to influence the distribution of infectious diseases, such as climate and other environmental factors. The ability to acquire relevant climatic information, particularly in the tropics, where there is an inadequate infrastructure for the collection of meteorological data, has

[1] Wellcome Trust Research Fellow, Department of Infectious Disease Epidemiology, Imperial College School of Medicine, London, England. Currently: Lecturer, Disease Control and Vector Biology Unit, London School of Hygiene and Tropical Medicine, Keppel Street, London WC1E 7HT, England (email: simon.brooker@lshtm.ac.uk). Correspondence should be sent to this author at the latter address.

[2] Epidemiologist, Partnership for Child Development, Department of Infectious Disease Epidemiology, Imperial College School of Medicine, London, England.

[3] Senior Laboratory Technician, Hôpital Général de Référence, N'Djamena, Chad.

[4] Senior Laboratory Technician, Hôpital Général de Référence, N'Djamena, Chad.

[5] Doctor, School Health Commission, Ministry of Health, N'Djamena, Chad.

[6] Education Officer, School Health Commission, Ministry of Education, N'Djamena, Chad.

[7] Zoology Research Fellow, Trypanosomiasis and Land Use in Africa Research Group, Department of Zoology, University of Oxford, Oxford, England.

[8] Head, International School Health Initiative, Human Development Division, The World Bank, Washington DC, USA.

Ref. No. **01-1480**

been enhanced by remote sensing (RS) techniques that can provide proxy environmental information derived from satellite sensors (*2, 3*). RS environmental variables have been used to explain the distribution of various infectious diseases, with direct application to disease control programmes (*4*). Understanding the environmental limits of infection can aid the targeting of national control strategies, as has been demonstrated for onchocerciasis (*5*) and filariasis (*6*). For the control of geohelminth and schistosome infections, current WHO recommendations are based on the concept of sample surveys within defined ecological zones (*7*). There is a need, however, for guidelines whereby health planners can identify such zones and, using population data, develop and conduct rapid and valid epidemiological surveys of different helminth species.

Understanding the environmental limits of infection can also improve our knowledge of helminth biology and epidemiology. Much of our understanding of the environmental sensitivity of helminth species comes from studies undertaken under experimental conditions. For example, experimental studies have identified the temperature at which the development of free-living stages occurs in the shortest time, as well as the minimum and maximum temperatures that represent the thermal limits of development (*8*). A major disadvantage of this approach is that the extent to which findings can be extrapolated to the field is not known. Some studies have investigated the outdoor development and survival of free-living stages of helminth species (*9, 10*) but it is not clear how specific they were to the setting in which they were conducted. In contrast, the use of RS environmental observations by satellite sensors allows quantitative measurements of key climatic variables at regular intervals on the regional scale (*3*). Using Advanced Very High Resolution Radiometer (AVHRR) Pathfinder satellite sensor data, we showed that the prevalence of *Ascaris lumbricoides* and *Trichuris trichiura* in Cameroon rarely exceeded 10% in areas where the RS-derived maximum land surface temperature exceeded 37–40 °C (*8, 11*). Furthermore, field studies in West Africa showed that *Schistosoma haematobium* occurred only throughout the Sahelian zone, because of the adaptation of the host snail *Bulinus senegalensis* to semipermanent water bodies in the Sahel (*12–14*). Using the same AVHRR Pathfinder satellite sensor data, it is possible to characterize these areas of potential schistosome transmission in Cameroon (*11, 15*). The correlations between observed disease patterns and RS environmental variables can also be used to extrapolate risk estimates to areas for which no data are available. It is unclear, however, whether predictions developed for one country are useful in describing infection patterns in another, since the environmental factors that influence disease transmission are unlikely to be uniform over large geographical areas (*15*).

Building on these investigations, we describe how a GIS/RS approach can be used to plan and conduct a rapid epidemiological assessment and to define the environmental limits of helminth species in Chad.

Methods

Remotely sensed proxy environmental data

In Chad, detailed meteorological observations are available for only five sites (*16*), which do not adequately capture the range of climatic conditions in the country as a whole. The poor spatial resolution of meteorological data was overcome by using remotely sensed environmental data derived from the AVHRR sensor on the US National Oceanic and Atmospheric Administration's (NOAA) polar-orbiting meteorological satellites. These data were used to calculate mean annual summaries for 1982–2000 of surface brightness temperatures (expressed as land surface temperature) and photosynthetic activity estimates, expressed as the normalized difference vegetation index. This involved standard procedures of data processing and quality control (*2*). Minimum, mean, and maximum values of remotely sensed data were used.

The accuracy of RS methods for providing estimates of temperature was investigated in Africa by comparing estimates of land surface temperature with meteorological ground measurements (*17, 18*). A significant correlation between land surface temperature and ground observations was found, with root mean square errors of around 2 °C (*17*). Thus the correlation between land surface temperature and ground observations is sufficiently strong for practical applications in epidemiological mapping.

Sampling design

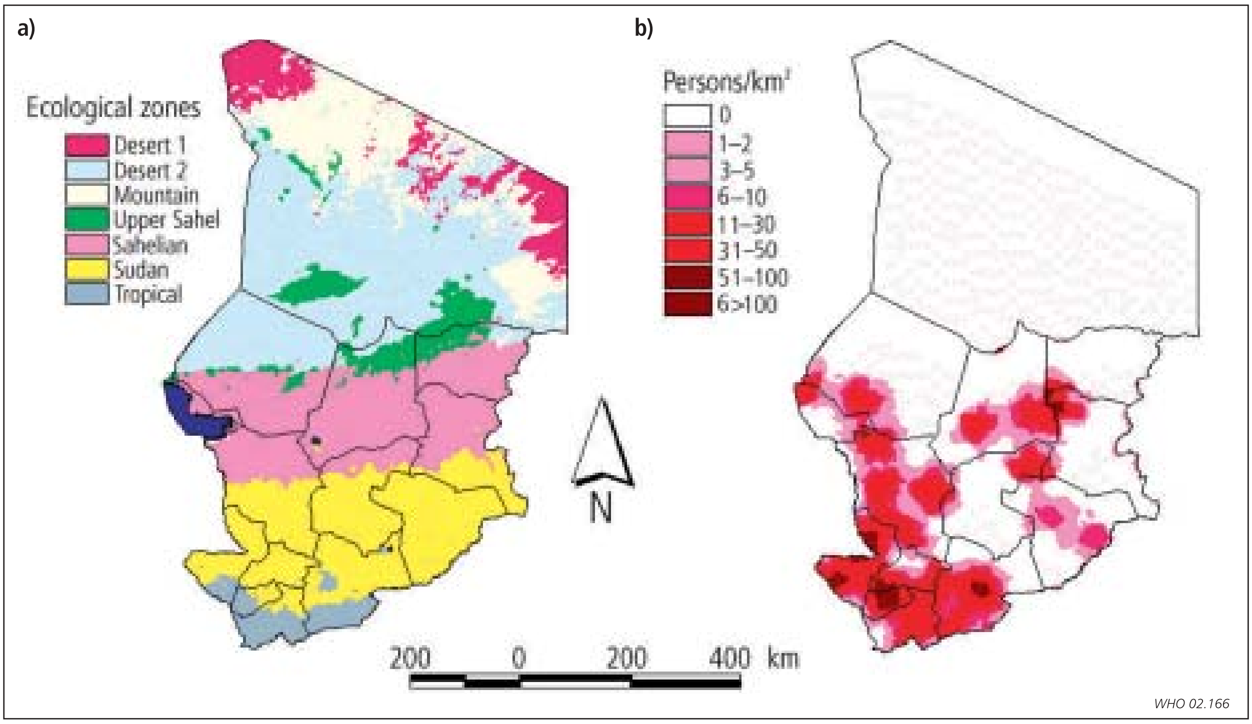
Stratified sampling by ecological zone overlaid with population data was used to select 20 schools. A map of ecological zones in Africa was derived from the RS environmental data described above. These data, in combination with a digital elevation model of Africa (available from: URL: http://edcwww.cr.usgs.gov/landdaac/gtopo30) and interpolated rainfall surfaces (*19*) were used to generate 20 ecological zones by means of the unsupervised classification procedures of Earth Resources Data Analysis System (ERDAS) Imagine 8.4™ software. ERDAS implements the iterative self-organizing data analysis technique, which uses Euclidean distance as a similarity measure to cluster data in discrete classes, independently of their geographical location (*20, 21*).

The resulting ecological map divides Chad into seven ecological zones (Fig. 1a). The map provides an overview of the main ecological variables known to be associated with different patterns and prevalences of helminth infection (*8*, *11*, *15*). Overlaying this map with data on population density (*22*) can help to guide the sample protocol. In the case of Chad, the survey focuses on the populous south-west of the country (Fig. 1b). In this area there are three ecological zones and an urban zone, the latter being the capital, N'Djamena. This is all the information required to target the sampling by ecological zone and population density. Logistical considerations meant that the sample had to be limited to 20 schools situated not more than 30 km from main roads. The number of schools sampled in each zone was proportional to the population. For example, because 10% of the country's population lives in the tropical zone, two schools were randomly selected.

Field investigations

The survey was conducted in November 2000. The target was to randomly select 25 boys and 25 girls aged 9–10 years (class 3). If there were insufficient pupils of this age, additional pupils were sampled from classes 4–7. Many of the schools visited were small, and female enrolment was low. Consequently, it was often necessary to include all the girls in a school in order to achieve the target sample size. In some cases fewer than 25 girls were present. Participation was voluntary and was approved by the local school committee and parents.

Fig. 1. **a) Ecological zones in Chad based on remote-sensing-derived variables and b) the population density in Chad** (*22*)



A faecal sample was collected from each child and examined using the Kato–Katz method; 10 ml of a urine specimen collected from each child were filtered through a polycarbonate membrane (diameter = 13 mm, pore size = 12 μm; Millipore, Watford, England) and examined microscopically. Each child infected with schistosomes received 40 mg/kg praziquantel and each child infected with geohelminth species received 400 mg albendazole. The geographical location of each school was recorded in the field by means of a non-differential global positioning system (Magellan Systems Corporation, San Dimas, CA, USA) accurate to ±10 m.

Data analysis

χ^2 and Student's *t*-tests were used to assess differences in the prevalence and intensity of infection, by sex. Analysis was also undertaken to investigate how key environmental variables correlated with infection patterns, as determined by the probability that an individual child was infected. Since variables were collected at the individual and school levels, a multilevel approach of logistic regression was employed, accounting for the non-independence of individual observations within schools. In particular, the use of multilevel modelling controlled for the considerable sampling bias in the study towards boys when investigating the environmental correlates of infection. The analysis was performed by means of generalized estimating equations (*23, 24*) with the *xtgee* procedure (logit link function and binomial distribution specified with robust standard errors, grouped by school) in Stata (Intercooled Stata 6.0, College Station, TX, USA). A forward stepwise procedure was used to screen the included explanatory variables ($P<0.05$).

Validation of RS prediction models for Cameroon

Statistical correlations between epidemiological data and RS environmental data were previously investigated in Cameroon (*8*, *11*). Multivariate logistic regression models were developed to identify the main predictors of helminth prevalence in school-age children exceeding 50% (the WHO-recommended threshold for mass treatment), 20%, and 0%. The significant environmental variables were maximum land surface temperature, rainfall and normalized difference vegetation index (*11*). No statistically significant model could be developed for hookworm. The statistical models derived from the data for Cameroon were applied to the RS data so as to define the probability of infection prevalence exceeding 50%, 20%, or 0% for the rest of Cameroon. We extended these predictions to Chad and compared them with the field data. This involved taking a 10-km buffer zone around each school and taking the average values of the pixels in each buffer zone (*1*).

Results

Of the 626 boys and 397 girls examined, over 90% were aged 8–13 years. Of the 1017 children who provided a urine sample, 22.5% were infected with *S. haematobium*. The intensity of infection with *S. haematobium* lay in the range 1–749 eggs per 10 ml, but generally the children were lightly infected: only 6.1% excreted over 50 eggs per 10 ml. Of the 1000 children who provided a stool sample, 32.7% were infected with hookworm (mean egg count = 180 eggs/g; range by school = 0–694 eggs/g). Both *S. haematobium* and hookworm were present in 7.1% of children. Seven children (1%) excreted *S. mansoni* eggs in their faeces. No children were infected with *A. lumbricoides* or *T. trichiura*.

Significantly more boys than girls were infected with *S. haematobium* (28.8% vs 12.7%, χ^2 test = 35, $P<0.0001$) and hookworm (35.8% vs 28.5%, χ^2 test = 5, $P = 0.03$). Boys were also more heavily infected than girls with *S. haematobium* (15.6 vs 9.4 eggs/10 ml, $P<0.05$) and hookworm (208 vs 132 eggs/g, $P<0.02$).

Fig. 2 shows the distribution of helminth infections in Chad by ecological zone. The prevalence of *S. haematobium* varied considerably between schools, being highest in the Sahelian zone and the Logone and Chari basins in the west of the country, and lowest in the N'Djamena and tropical zones. Hookworm was most prevalent in the Sudan and tropical zones; there was little or no transmission in the Sahelian zone. Neither *A. lumbricoides* nor *T. trichiura* occurred anywhere in the country at detectable levels.

Table 1 presents infection patterns and their associated environmental variables by ecological zone. Areas of high *S. haematobium* prevalence had low rainfall and high mean land surface temperatures. However, this was also true of N'Djamena, where the prevalence of *S. haematobium* was under 5%. Substantial hookworm infection occurred in the Sudan and tropical zones, whereas there was little or no hookworm infection in N'Djamena or the Sahelian zone, where the mean land surface temperature exceeded 47 °C. Table 2 shows the results of the multivariate analyses as odds ratios for being infected. Boys were 2.4 times more likely than girls to be infected with *S. haematobium*. Mean land surface temperature and rainfall were significantly associated with *S. haematobium* infection. For hookworm, increasing mean land surface temperature was associated with a reduced chance of being infected.

On the basis of models developed in Cameroon (*11*), we predicted the prevalence of infection category (0, 20, or 50%) for each school surveyed. These models predicted that *A. lumbricoides* and *T. trichiura* would not occur in Chad because the mean land surface temperature exceeds 37 °C throughout the country. The results of the present study confirm this, since *A. lumbricoides* and *T. trichiura* did not occur anywhere at detectable levels. No suitable model could be developed for hookworm and therefore no predictions are given for it. For *S. haematobium* the predictions (nine schools with prevalences of infection exceeding 50%) were less reliable, since only one school had this level of infection. It was also predicted that all schools would have prevalences of infection exceeding 20% but this was the case in only four schools.

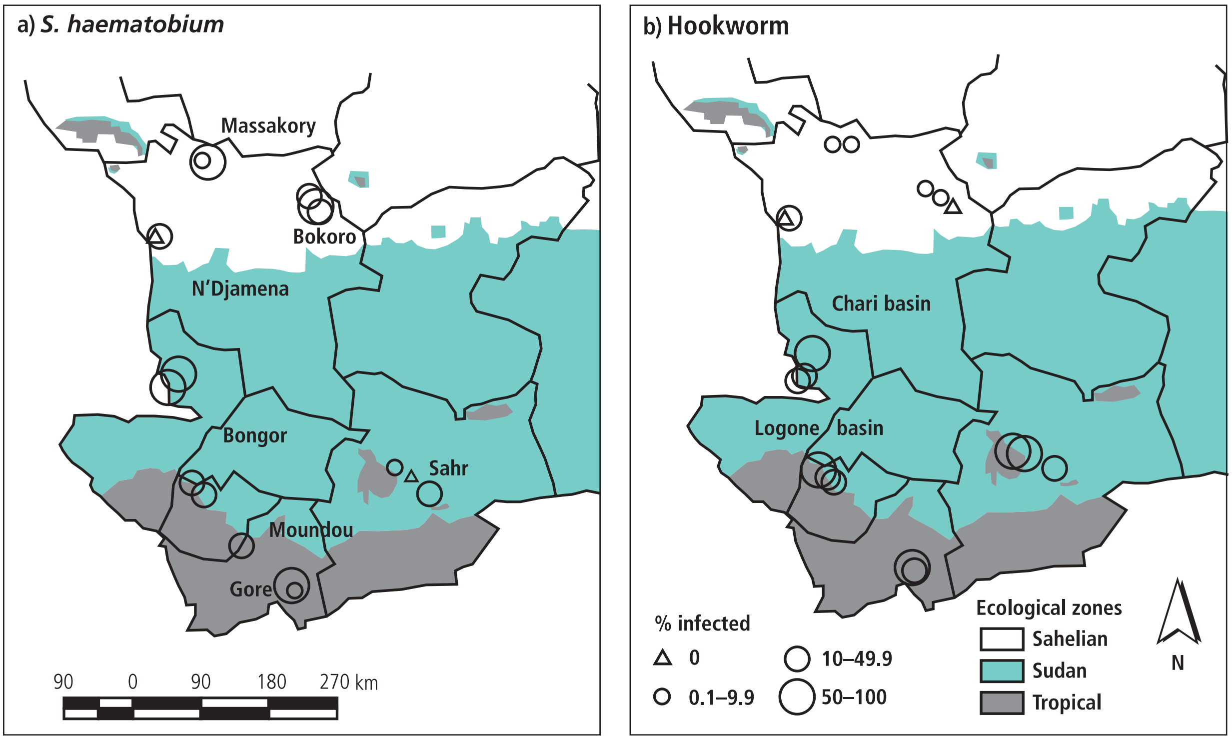
Discussion

The present study on helminth infections in Chad describes the use of GIS and RS to guide a valid rapid epidemiological survey of different helminth species as a basis for developing a national control programme. The study also predicts the environmental limits of several helminth species in the country. The results confirm that *A. lumbricoides* and *T. trichiura* should not occur in Chad because the mean land surface temperature exceeds 37 °C throughout the country (*8*, *11*). Such predictions are supported by experimental data: *T. trichiura* eggs take about 28 days to develop at 25 °C, 15 days at 30 °C and 13 days at 34 °C, and do not develop at all above 37 °C (*25*). The optimal temperature for the embryonation of *Ascaris* spp. is 31 °C (*26*); 38 °C is lethal (*26*, *27*). These values and the present data confirm an upper thermal limit of around 37 °C for both *A lumbricoides* and *T. trichiura*.

Ecological limits of hookworm

Previous studies have failed to identify ecological correlates of hookworm infection (*11*). Our previous work in Cameroon suggested that this reflected the absence of differential diagnosis of hookworm species or the predominance of behavioural factors. However, the present results suggest that

Fig. 2. **Distribution of a) *Schistosoma haematobium* and b) hookworm among schoolchildren from 20 schools in Chad**
(NB: the keys apply to both maps)



WHO 02.167

Table 1. **Infection prevalences and key environmental variables by ecological zone, Chad**

Zone	Median infection prevalence (%)		Land surface temperature (°C)		Total rainfall (mm)
	Hookworm	*Schistosoma haematobium*	Mean	Maximum	
N'Djamena	0.0	2.0	47.9	55.9	533
Sahelian[a]	3.6	37.3	49.4	56.8	491
Sudan	44.4	18.0	44.1	55.1	997
Tropical	76.0	2.0	41.0	52.5	1157

[a] Not including N'Djamena.

Table 2. **Details from multivariate analysis used to estimate probability of a child being infected, in 20 schools, Chad**

	Odds ratio	Robust standard error	Significance
Schistosoma haematobium			
Sex	2.40	0.43	$P < 0.001$
Mean land surface temperature	3.66	1.29	$P < 0.001$
Rainfall	1.01	0.003	$P < 0.001$
Hookworm			
Mean land surface temperature	0.70	0.07	$P < 0.001$

hookworm occurs only in the south of Chad and that there is little or no infection in areas where the mean land surface temperature exceeds 47 °C. This distribution pattern probably defines the upper thermal limit of hookworm infection, which is apparently greater than that for *A. lumbricoides* and *T. trichiura* (37 °C). This species difference in observed thermal limits is corroborated by survey data for Mali (*28*), where *A. lumbricoides* and *T. trichiura* occur at negligible levels (<0.5%) and hookworm occurs in areas where the mean land surface temperature exceeds 40 °C. This limit differs from that found in experimental studies showing that egg development stops and death occurs above 35–40 °C (*9*, *10*, *29*). For example, Udonsi & Atata (*9*) showed that at 35 °C the larvae of *Necator americanus* all died and that the highest cumulative hatching occurred at 30 °C. Given these findings and allowing for potential error in RS estimates (± 2 °C), the question arises as to why hookworms apparently have a thermal limit of 48 °C and why this exceeds that for either *A. lumbricoides* or *T. trichiura*.

One possible explanation for our findings is that microhabitats provide suitable foci for hookworm transmission in areas of high temperature. However, this argument would be expected to hold also for *A. lumbricoides* or *T. trichiura*. Alternatively, hookworm might undergo arrested development in order to achieve synchronization with external conditions (*30*), although this is observed only for *Ancylostoma duodenale*, whereas *N. americanus* is the predominant species in Africa. Another explanation might lie in the differences in the life expectancies of mature worms in the human host: 3–4 years for hookworm and 1–2 years for *A. lumbricoides* and *T. trichiura* (*31*). Research is in progress on this hypothesis.

Other helminths

Predictions for Cameroon indicated that *S. haematobium* could potentially occur throughout the Sahelian zone (*11*, *15*), where transmission take places in areas with semipermanent water bodies and with *Bulinus senegalensis* as the most likely intermediate host (*12*). These predictions are much less reliable than those relating to *A. lumbricoides* and *T. trichiura*. The lack of predictive accuracy for *S. haematobium* supports the view that it is not possible to make prediction models for schistosomiasis that are applicable at the local level (*15*). Rather, large-scale models are useful for identifying potential areas of high risk. In particular, they can help to exclude areas where *S. haematobium* is unlikely to be prevalent and thus indicate areas where local detailed surveys are required so that control can be targeted more precisely. In the present study, all the schools were predicted to be in areas of potential high risk, but local environmental factors presumably determined the actual levels of transmission. For example, the Logone and Chari river basins constitute important foci of schistosomiasis transmission, verifying earlier field studies (*32, 33*). In these areas, where rice production is common, there are stagnant ponds and irrigation ditches capable of supporting populations of *Bulinus globosus* and *B. truncatus* throughout the year (*34*). These findings illustrate the importance of considering the occurrence of man-made features and other small-scale environmental factors that are not readily detectable in large-scale RS data. A simple questionnaire, administered by teachers to their pupils, can be used to identify individual schools where the prevalence of *S. haematobium* is ⩾50% and therefore warrant mass treatment (*35*).

Conclusion

The objective of the present national survey was to determine the distribution of helminth infection within the country and to contribute towards planning school-based control programmes, for which purpose it is essential to estimate the target population. The population of Chad in 2000 was estimated to be 8.4 million, of whom 2.4 million were aged 5–14 years.[a] Assuming that the survey results within each zone are representative, they allow the school-age population at risk of schistosomiasis and hookworm transmission to be quantified. On this basis, it is estimated that 1.7 million children in nine districts would be the target for mass treatment for hookworm and that 1.3 million children in eight districts would be the target for a school-based national schistosomiasis control programme, which would include questionnaire screening at the school level. Estimates for school-based programmes suggested that the overall cost per child treated with albendazole for geohelminth control was US$ 0.03 in Ghana and United Republic of Tanzania, and that the costs per child treated with praziquantel for schistosomiasis control were US$ 0.67 and US$ 0.21, respectively, in these two countries (*36*). Thus it would cost approximately US$ 51 000 for a

[a] Data on the school-age population for every district were based on 1990 national population forecasts (*22*), projected to 2001 on the assumption of country- and year-specific inter-census growth rates (See: URL: http://www.census.gov/ipc/www/idbnew.html).

school-based programme of geohelminth control and US$ 273 000–871 000 for a school-based schistosomiasis control programme in Chad.

The present study demonstrates the important role of RS and GIS in planning national helminth surveys, which are an essential prelude to planning the deworming component of national school health initiatives. The use of ecological zone maps is shown to be of value in defining sampling clusters without the need for any ground-based ecological surveys. Multilevel methods are useful in investigating the relationships between infection patterns and environmental variables, and show the importance of temperature in defining the ecological limits of hookworm infection, and of temperature and rainfall in characterizing areas of high prevalence of *S. haematobium*. We have also shown that RS data can reliably predict the occurrence of geohelminth species. The approach can predict only the potential risk of schistosome transmission, and local questionnaire surveys are needed to target control more precisely. The use of RS data should now be investigated in other epidemiological and ecological settings in order to obtain further validation of the adopted approach. Perhaps more importantly, the challenge for epidemiologists is to demonstrate how this approach is of practical relevance to control programmes. ■

Acknowledgements

The fieldwork was supported by the Partnership for Child Development, The World Bank, and the Wellcome Trust. The survey was conducted at the request of the School Health Commission of Chad and forms part of the preparation of the School Health Component of the Chad Quality Education for All Project, supported by the World Bank. We thank Mourad Ezzine, Alan Dock, Lesley Drake, Kaiolanoum Léa, Seung-hee Lee, Matthew Jukes, N'Gooyo Madeleine, Celia Maier, Jean-Pierre Moula-Pelat, David J. Rogers and William Wint for their input. The following formal acknowledgement is requested of those who use Pathfinder AVHRR Land data: "Data used in this study include data produced through funding from the Earth Observing System Pathfinder Program of NASA's Mission to Planet Earth in cooperation with the National Oceanic and Atmospheric Administration. The data were provided by the Earth Observing System Data and Information System (EOSDIS), Distributed Active Archive Center (DAAC) at Goddard Space Flight Center which archives, manages and distributes this dataset". S. Brooker is supported by a Wellcome Trust Prize Fellowship (No. 062692) and S.I Hay is supported by a Wellcome Trust Advanced Training Fellowship (No. 056642).

Conflicts of interest: none declared.

Résumé

Utilisation de la télédétection et d'un système d'information géographique dans un programme national de lutte contre les helminthes au Tchad

Objectif Planifier et mettre en œuvre une évaluation épidémiologique rapide et correcte de la présence d'helminthes chez des écoliers du Tchad en se basant sur des zones écologiques définies grâce à des données de télédétection par satellite, et chercher à établir les limites environnementales de la distribution des helminthes.

Méthodes Des données environnementales indirectes obtenues par télédétection ont été utilisées pour définir sept zones écologiques au Tchad. Ces données ont été combinées avec des données de population dans un système d'information géographique (SIG) en vue de définir un protocole d'échantillonnage, lequel a conduit à réaliser une enquête dans 20 écoles. Une analyse à plusieurs niveaux a été effectuée au moyen d'équations de généralisation pour tenir compte du regroupement des cas au niveau des écoles afin d'étudier la relation entre le tableau épidémiologique de l'infection et certaines variables environnementales.

Résultats Sur un échantillon de 1023 écoliers, 22,5 % étaient infectés par *Schistosoma haematobium* et 32,7 % par des ankylostomes. Aucun d'entre eux n'était infecté par *Ascaris lumbricoides* ni par *Trichuris trichiura*. La prévalence de *S. haematobium* et des ankylostomes présentait une forte hétérogénéité géographique et la répartition observée montrait une association étroite avec les zones écologiques définies et une relation significative avec les variables environnementales. Ces résultats contribuent à définir les limites thermiques de la distribution des différentes espèces de géohelminthes. Des prévisions de la prévalence de l'infection ont été réalisées pour chaque école enquêtée à l'aide des modèles déjà établis pour le Cameroun. Ces modèles ont correctement prévu l'absence de *A. lumbricoides* et de *T. trichiura* au Tchad mais les prévisions concernant *S. haematobium* étaient moins fiables au niveau des écoles.

Conclusion Les SIG et la télédétection peuvent jouer un rôle important dans la planification rapide des programmes de lutte contre les helminthes lorsqu'on ne dispose que de peu d'informations sur la charge de morbidité. Les modèles de prévision tirés des données de la télédétection peuvent indiquer la répartition générale des infections à géohelminthes mais ne peuvent qu'identifier les zones à haut risque potentielles pour *S. haematobium*.

Resumen

Uso de la teleobservación y de un sistema de información geográfica en un programa nacional de lucha contra los helmintos en el Chad

Objetivo Diseñar y aplicar un sistema de evaluación epidemiológica rápida y válida de las helmintiasis entre los escolares en el Chad utilizando zonas ecológicas definidas por los datos de un satélite de teleobservación, e investigar los límites ambientales de la distribución de los helmintos.

Métodos Se utilizaron datos ambientales indirectos de teleobservación para definir siete zonas ecológicas en el Chad. Dichos datos se combinaron con datos demográficos en un sistema de información geográfica (SIG) para definir un protocolo de muestreo. Sobre esta base, se analizaron 20 escuelas. Se realizó un análisis jerarquizado, usando ecuaciones de estimación generalizadas a fin de tener en cuenta el agrupamiento a nivel de las escuelas, para investigar la relación entre los modelos de infección y variables ambientales clave.

Resultados En una muestra de 1023 escolares, el 22,5% estaban infectados por *Schistosoma haematobium,* y el 32,7% por anquilostoma. Ninguno estaba infectado por *Ascaris lumbricoides* o *Trichuris trichiura*. La prevalencia de *S. haematobium* y de anquilostoma mostró una marcada heterogeneidad geográfica, y la distribución observada resultó estar estrechamente relacionada con las zonas ecológicas definidas, y ligada de forma importante a variables ambientales. Estos resultados permiten definir más fácilmente los límites de temperatura de las especies de geohelmintos. Se hicieron predicciones de la prevalencia de las infecciones para cada escuela analizada con la ayuda de modelos desarrollados anteriormente para el Camerún. Estos modelos predijeron correctamente que *A. lumbricoides* y *T. trichiura* no se detectarían en el Chad, pero las predicciones para *S. haematobium* fueron menos fiables a nivel de las escuelas.

Conclusión Los SIG y la teleobservación pueden ser instrumentos valiosos para planificar rápidamente programas de lucha antihelmíntica cuando se dispone de poca información sobre la carga de morbilidad. Los modelos predictivos basados en la teleobservación pueden indicar la distribución de las infecciones por geohelmintos, pero sólo logran identificar las zonas potenciales de alto riesgo de infección por *S. haematobium*.

References

1. Burrough PA, McDonnell RA. *Principles of geographical information systems*. Oxford: Oxford University Press; 1998.
2. Hay SI. An overview of remote sensing and geodesy for epidemiology and public health applications. *Advances in Parasitology* 2000;47:2-27.
3. Goetz SJ,Prince SD, Small J. Advances in satellite remote sensing of environmental variables for epidemiological applications. *Advances in Parasitology* 2000;47:289-307.
4. Hay SI, Randolph S, Rogers DJ. *Remote sensing and geographical information systems in epidemiology*. London: Academic Press; 2000.
5. Ngoumou P, Walsh JF, Mace JM. A rapid mapping technique for the prevalence and distribution of onchocerciasis: a Cameroon case study. *Annals of Tropical Medicine and Parasitology* 1994;88:463-74.
6. Lindsay SW, Thomas CJ. Mapping and estimating the population at risk from lymphatic filariasis in Africa. *Transactions of the Royal Society of Tropical Medicine and Hygiene* 2000;94:37-44.
7. Montresor A, Crompton DWT, Hall A, Bundy DAP, Savioli L. *Guidelines for the evaluation of soil-transmitted helminthiasis and schistosomiasis at the community level*. Geneva: World Health Organization; 1998.WHO document WHO/CTD/SIP/98.1. Available from: URL: http://whqlibdoc.who.int/hq/1998/WHO_CTD_SIP_98.1.pdf
8. Brooker S, Michael E. The potential of geographical information systems and remote sensing in the epidemiology and control of human helminth infections. *Advances in Parasitology* 2000;47:245-88.
9. Udonsi JK, Atata G. *Necator americanus*: temperature, pH, light, and larval development, longevity, and desiccation tolerance. *Experimental Parasitology* 1987;63:136-42.
10. Nwosu ABC. Investigations into the free-living phase of the cat hookworm life-cycle. *Zeitschrift für Parasitenkunde* 1978;56:243-9.
11. Brooker S, Hay SI, Tchuem Tchuenté LA, Ratard R. Modelling human helminth distributions for planning disease control in Cameroon. *Photogrammetric Engineering and Remote Sensing* 2001;68:175-9.
12. Wright CA. A note on the distribution of *Bulinus senegalensis*. *West African Medical Journal* 1959;8:142-8.
13. Buck AA, Anderson SI, Sasaki TT, Kawata K. *Health and disease in Chad. Epidemiology, culture and environment in five villages*. Baltimore (MD): The John Hopkins Press; 1970.
14. Greer GJ, Mimpfoundi R, Malek EA, Joky A, Ngonseu E, Ratard RC. Human schistosomiasis in Cameroon II. Distribution of the snail hosts. *American Journal of Tropical Medicine and Hygiene* 1990;6:573-80.
15. Brooker S, Hay SI, Bundy DA. Tools from ecology: useful for evaluating infection risk models? *Trends in Parasitology* 2002;18:70-4.
16. National Oceanic and Atmospheric Administration. *Monthly climate data for the world*, vols. 41–43. Asheville, North Carolina: National Climate Data Center, National Oceanic and Atmospheric Administration; 1990.
17. Green RM, Hay SI. The potential of Pathfinder AVHRR data for providing surrogate climatic variables across Africa and Europe for epidemiological applications. *Remote Sensing of Environment* 2002;79:166-75.
18. Hay SI, Lennon JJ. Deriving meteorological variables across Africa for the study and control of vector-borne diseases: a comparison of remote sensing and spatial interpolation of climate. *Tropical Medicine and International Health* 1999;4:58-71.
19. Corbett JD, O'Brien RF. *The spatial characterization tool — Africa v1.0*. Blackland Research Center Report No. 97-03, Documentation and CD ROM, Texas A & M University; 1997. URL: http://www.brc.tamus.edu/char/SCT.html Blackland Research Center Report No. 97-03, Documentation and CD ROM.
20. Jensen JR. *Introductory digital image processing. A remote sensing perspective*, Saddle River, NJ: Prentice-Hall; 1996. p. 197-256.
21. Rogers DJ, Wint W. *Towards identifying priority areas for tsetse control in East Africa. Oxford: Consultants' Report to the Food and Agriculture Organization on Trypanosomiasis and Land Use in Africa*, Rome: FAO; 1996.
22. Deichmann U. *African population database documentation*. National Center for Geographic Information and Analysis, University of California, Santa Barbara, CA, USA. Available from: URL: http://grid2.cr.usgs.gov/globalpop/africa/
23. Liang KY, Zeger SL. Regression analysis for correlated data. *Annual Review of Public Health* 1993;14:43-68.
24. McDermott JJ, Schukken YH. A review of methods used to adjust for herd effects in explanatory epidemiological studies of animal population. *Preventive Veterinary Medicine* 1994;18:155-74.
25. Beer RJ. The relationship between *Trichuris trichiura* (Linnaeus 1758) of man and *Trichuris suis* (Schrank 1788) of the pig. *Research in Veterinary Science* 1976;20:47-54.
26. Seamster AP. Developmental studies concerning the eggs of *Ascaris lumbricoides* var. *suum*. *The American Midland Naturalist* 1950;43:450-68.
27. *Control of ascariasis. Report of a WHO Expert Committee*. Geneva: World Health Organization; 1967.
28. De Clercq D, Sacko M, Behnke JM, Traore M, Vercruysse J. *Schistosoma* and geohelminth infections in Mali, West Africa. *Annales de la Société belge de Médecine Tropicale* 1995;75:191-9.
29. Smith G, Schad GA. *Ancylostoma duodenale* and *Necator americanus*: effect of temperature on egg development and mortality. *Parasitology* 1990;99: 127-32.
30. Schad GA, Chowdhury AB, Dean CG, Kochar VK, Nawalinski TA, et al. Arrested development in human hookworm infection: an adaptation to seasonally unfavourable external environment. *Science* 1973;180:502-4.
31. Anderson RM, May RM. *Infectious diseases of humans: dynamics and control*. Oxford: Oxford University Press; 1991.
32. Gaud J. [Bilharziasis in French West and Central Africa.] *Bulletin of the World Health Organization* 1955;13:209-58. In French.
33. Gigase PL, Mangelschots E, Bockaert R, Autier P, Kestens L. [Indicateurs simples de la prevalence et de l'intensité de la bilharziose urinaire au Tchad.] *Annales de la Société belge de Médecine Tropicale* 1988;68:123-32.
34. Doumenge JP. *Atlas of the global distribution of schistosomiasis*. Bordeaux: Presses Universitaires de Bordeaux; 1987.
35. Red Urine Study Group. Identification of high risk communities for schistosomiasis in Africa: a multi-country study. Geneva: UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases; 1995. Social and Economic Research Project Reports, No: 15. Available from: URL: http://whqlibdoc.who.int/hq/1995/TDR_SER_PRS_15.pdf
36. Partnership for Child Development. The cost of large-scale school health programmes which deliver anthelmintics in Ghana and Tanzania. *Acta Tropica* 1999;73:183-204.