MAPPING SOIL-TRANSMITTED HELMINTHS IN SOUTHEAST ASIA AND IMPLICATIONS FOR PARASITE CONTROL

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Abstract. Establishing the current status and distribution of soil-transmitted helminths is essential for developing and implementing parasite control. Although Southeast Asia is known to have a high prevalence of infection, a precise estimate of the total disease burden has not been fully described. Here, we use Geographical Information Systems (GIS) to collate and map recent published surveys on soil-transmitted helminth epidemiology and distribution for this region. Distinct geographical variation was observed, which is suggested to reflect climatic variation, as well as behavioral differences. However, for much of the region few data are available, and therefore it proved necessary to generate predictions of the distribution of soil-transmitted helminths using remotely sensed (RS) satellite sensor environmental variables. A significant finding was the importance of land surface temperature in influencing the distribution of *Ascaris lumbricoides* and *Trichuris trichiura*. Spatial analyses using RS satellite sensor data were then used to generate predictive maps of infection risk. This information provided the basis for an estimate of the population at risk of infection and the numbers requiring treatment. These applications of GIS and remote sensing provide a good basis for developing control of soil-transmitted helminths in the region.

INTRODUCTION

Although Southeast Asia is known to have a high prevalence of soil-transmitted helminth infections (*Ascaris lumbricoides*, *Trichuris trichiura* and hookworm) (Urbani and Palmer, 2001), a precise estimate of the total disease burden has not been fully described. Yet, renewed interest by governments and international organizations in helminth control has led to an increased impetus to attain comprehensive data, allowing available control resources to be most rationally and cost-effectively deployed. In concert with these changes in international health priorities, there have been developments in methods to map and analyze epidemiological information. Geographical information systems (GIS) are increasingly being used to collate and map available epidemiological data and have been used in several studies mapping disease distributions: for example, filariasis in Vietnam (Meyrowitsch *et al*, 1998), India (Sabesan *et al*, 2000) and globally (Michael and Bundy, 1997); malaria in Kenya (Omumbo *et al*, 1998); and helminths in Africa (Brooker *et al*, 2000). In addition, advances in the use of remotely sensed (RS) satellite sensor data to derive indirect estimates of environmental variables has increased our ability to map the spatial risk of disease at broad spatial scales (Hay *et al*, 2000). For soil-transmitted helminths, these applications of GIS and RS data have only been attempted in Africa (Brooker *et al*, 2000; 2002). Extending such an approach, the present

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study reports on the mapping of helminth infections in Southeast Asia. Our first objective was to use GIS to collate and map available prevalence data both from the published literature and local sources. Our second objective was to apply spatial analyses to prevalence data and RS satellite sensor data, and identify ecological correlates of infection patterns in order to generate predictive maps of infection risk. This information provided the basis for an estimate of the population at risk of infection and the numbers requiring treatment.

MATERIALS AND METHODS

Geographical information systems database

An extensive computer literature review and manual reference tracing was undertaken to identify studies which reported data on the prevalence of helminth infection in Southeast Asia. Further data were obtained from unpublished results of surveys conducted by government institutions. Only community-based, cross-sectional surveys were selected for inclusion. Data were excluded if they came from hospital surveys, post-intervention surveys or refugee studies (as these tend to be biased samples), if they did not provide the sample size and/or the number positive (necessary to undertake the weighted analysis), or if there were inconsistencies in the calculations presented. Included data were incorporated into a standardized database format [see Brooker *et al* (2000) for inclusion criteria].

Survey data were then mapped at the second administrative level – here defined as the province. The province in which each survey was undertaken was identified and linked to province boundary maps provided by HealthMap, WHO (http://www.who.int/emc/healthmap/healthmap.html). Mean prevalences were calculated for the provinces in which more than one survey had been conducted by taking the weighted mean of the individual survey prevalences, with weights given according to sample size. Because of the paucity of age-stratified data, community prevalence estimates are given.

Province-level population data were derived from most recent population estimates available from national census agencies in Cambodia (http://www.nis.gov.kh/Statistics.htm) and Thailand (http://www.nso.go.th/eng/index.htm). For Lao PDR, Myanmar, and Vietnam estimates were derived from a modelled 1990 regional population forecast (Deichmann, 1996) that are projected to 2002 using country- and year-specific growth rates obtained from the US Census Bureau (2002). Estimates of the proportion of school-age children (5-14 years) in each country were derived from national census information: Cambodia (0.30); Lao PDR (0.267); Myanmar (0.198); Thailand (0.168) and Vietnam (0.219). In each country, these values were applied to all provinces for reasons of consistency.

Modelling helminth distributions using RS data

GIS methods were used to integrate survey data with remotely sensed (RS) satellite sensor environmental data. Land Surface Temperature (LST) and Normalized Difference Vegetation Index (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. Daily data at 8x8 km spatial resolution data were first processed for the period 1985-2001 to exclude unreliable pixels due to extreme sun and sensor viewing angles and cloud contamination [for further details see Hay (2000)]. Single monthly images were generated by taking the maximum pixel value over a monthly period, a technique called maximum value compositing, to further reduce atmospheric contamination. Average annual minimum, mean and maximum values of these monthly data were used in the present analysis. Image processing was performed using the Earth Resources Data Analysis System (ERDAS) Imagine 8.4™ (ERDAS, Inc, Atlanta, GA) and geographical data were displayed using ArcView (Version 3.2 ERSI, CA, 1998).

Data from a national survey in Vietnam

(the only national survey in the region) were used to investigate the association between infection patterns and the above-mentioned RS-derived environmental variables. For each province in Vietnam, the median value of pixels within province boundaries was calculated and used in the analysis. Logistic regression was used in the analysis, using S-Plus 2000 (Math Soft, Seattle, WA). A number of different models were fitted to the data and residual deviances were compared to identify the best-fit models. 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 (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 assessed. Added next to the model analysis were NDVI (minimum, maximum and mean), rainfall and altitude. The statistical fit of the models was expressed as the residual deviance and alternative models were compared using a χ^2 distribution (Venables and Ripley, 1999) until a parsimonious model was identified. The coefficients of the final models were then applied to the RS images to develop the predictive maps of infection prevalence using the raster-based image processing software IDRISI for Windows (Version 2.0, Clark University, 1997).

To define whether a province would be a priority area for control, we have used a prevalence threshold of 50% (WHO's recommended threshold for mass treatment). For Vietnam, the predictive accuracy of the model predictions was measured by the percentage of provinces correctly classified using the 50% prevalence threshold and assessed using Kappa statistic (Landis and Koch, 1977). Values of Kappa less than 0.4 indicate poor agreement, values between 0.4-0.75 suggest good agreement, and values above 0.75, excellent agreement. Estimates for schoolchildren are provided since they are the primary targets for treatment and the educational infrastructure is usually used to deliver treatment.

RESULTS

Distribution of helminth infection in Southeast Asia

The number of surveys available for each country varies considerably (Table 1). Only Vietnam has comprehensive survey data at the province level (Anon, 1995). Survey data are particularly sparse for Lao PDR, Cambodia and Myanmar at present. Data on soil-transmitted helminths are available for 3 (15.8%) of the 19 provinces in Cambodia; 5 (29.4%) of the 17 in Lao PDR; 6 (42.9%) of the 14 for Myanmar; 32 (44.4%) of the 72 for Thailand; and 52 (98.1%) of the 53 provinces in Vietnam. Much of the published data, especially for Myanmar and Thailand, are more than 10 years old, making extrapolations to the present day uncertain.

The distribution of helminth infection prevalence by species and province is shown in Fig 1. For each helminth species, infection prevalence varies considerably across the region. Fig 1a and 1b show that high prevalences of *A. lumbricoides* and *T. trichiura* are found in the Red River Delta Region in northern Vietnam and the Mekong River Delta in southern Vietnam, and in the northern and southern regions of Myanmar. In contrast, the central provinces of Thailand and Vietnam are found to have the lowest prevalences. Hookworm infection prevalence varies across the region in no clear pattern (Fig 1c): moderate prevalences (20-49.9%) are found in central Thailand and some areas of Vietnam; other provinces in Vietnam and southern Thailand have high prevalence (50% and above).

These data, however, come from many cross-sectional surveys and ignore differences in sampling methods and sites, sample sizes and diagnostic techniques making different comparisons difficult. A more useful approach would be model helminth distributions using data from a single survey, which includes comprehensive data.

Modeled helminth distributions

We used therefore the data from Vietnam

Table 1
Summary descriptives of the database on the prevalence of infection in Southeast Asia among pre-school children, school-aged children, and adults.

Country	Locality	Date	Age groups and number examined[a]				Species[b]	Source
			Pre-school	School-age	Adults	Total		
Cambodia	Takeo Province	1984	126	196	931	1,253	As, Tr, Hk	Giboda (1985)
Cambodia	Kracheh and Stoeng Treng Provinces	1998		2,547		2,547	As, Tr, Hk	Urbani *et al* (2001)
Lao PDR	Vientiane	1971	350	972	928	2,493	As, Tr, Hk	Sornmani *et al* (1974)
Lao PDR	7 districts in Vientiane Province	1997	362	837	1,934	3,133	As, Tr, Hk	Phetsouvannh *et al* (2001)
Lao PDR	Keoudom, Vientiane Province	1989	109	255	412	777	As, Tr, Hk	Giboda *et al* (1991)
Lao PDR	Ban Nanin, Vientiane Province	1989			100	100	As, Tr, Hk	Pholsena *et al* (1991)
Lao PDR	Mahaxay district, Khammouane Province	1995	54	74		128	As, Tr, Hk	Kobayashi *et al* (1996)
Lao PDR	Pakse, Champassak Province	1995		47	90	137	As, Tr, Hk	Chai and Hongvanthong (1998)
Lao PDR	Khammouane Province	1996				669	As, Tr, Hk	Vannachone *et al* (1998)
Lao PDR	Bolikhamxay Province	1998	247	447		709	As, Tr, Hk	Hohmann *et al* (1998)
Myanmar	Okpo, Rangoon Province	1969	86	180	405	671	As, Tr, Hk	Tu *et al* (1970)
Myanmar	Okpo, Rangoon Province	1982				783	As	Thein-Hlaing *et al* (1984)
Myanmar	Daikkan, Rangoon Province	1984				294	As	Thein-Hlaing *et al* (1991)
Myanmar	Dayebo, Rangoon Province	1969	72	153	346	571	As, Tr, Hk	Hpay *et al* (1970)
Myanmar	Kyaunggon, Rangoon Province	1962				426	As, Tr, Hk	Kyaw-Tint (1963)
Myanmar	Aroomdum, Kachin State	1965				79	As, Tr, Hk	Tu (1966)
Myanmar	Inle Lake, Shan State	1967				107	As, Hk	Tu and Hkun-Saw-Lwin (1968)
Myanmar	Aungsanmyo, Rangoon Province	1967				3,882	As, Tr, Hk	Ba-Tun and Ko-Ko (1968)
Myanmar	Shantegyi, Rangoon Province	1969				125	As, Tr, Hk	Khin-Kyi-Nyunt *et al* (1969)
Myanmar	Tuywinbo, Mandalay Province	1969				55	As	Khin-Kyi-Nyunt *et al* (1969)
Myanmar	Bassein West, Irrawaddy Province	1968				393	As, Tr, Hk	Hla-Myint *et al* (1969)
Myanmar	Rangoon, Rangoon Province	1969		2,200		2,200	As, Tr, Hk	Hla-Myint (1970)
Myanmar	Mandalay Province	1969				304	As, Tr	Tu *et al* (1970)
Myanmar	Loi-Kaw, Kayah State	1969				92	As, Tr, Hk	Khin-Ohn-Lwin (in Tu *et al*, 1970)
Thailand	Korat Province	1971	34	154	188	376	As, Tr Hk	Papasarathorn *et al* (1975)
Thailand	28 provinces	1981	4,305	13,125	21,854	43,339	As, Tr, Hk	Preuksaraji *et al* (1983)
Thailand	Khao Dam, Thong Pha Phoom	1981	64	58	206	328	As, Tr, Hk	Temcharoen *et al* (1987)
Thailand	Srinakarin Dam, Thong Pha Phoom	1981	41	54	119	214	As, Tr, Hk	Temcharoen *et al* (1987)
Thailand	Ubolratana Dam, Thong Pha Phoom	1981	49	165	230	444	As, Tr, Hk	Temcharoen *et al* (1987)
Thailand	Nai Tone, Phangna Province	1983				1,142	As, Tr, Hk	Upatham *et al* (1989)

Thailand	Boh Saen, Phangna Province	1983			518	518	As, Tr, Hk	Upatham *et al* (1989)
Thailand	Nakohon Nayok Province	1985				744	As, Tr, Hk	Setasuban *et al* (1989)
Thailand	Nakhon Si Thammarat Province	1999		617		617	As, Tr, Hk	Anantaphruti *et al* (2000)
Thailand	6 villages in Phichit Province	1978				676	As, Tr, Hk	Bunnag *et al* (1980)
Vietnam	17 schools in Nam Ha Province	1995		1,003		1,003	As, Tr, Hk	Vietnam PCD (1996)
Vietnam	Thuy Loi, Nam Ha Province	1996	26	185	332	543	As, Tr, Hk	Needham *et al* (1998)
Vietnam	Can Tho Province	1967				409	As, Tr, Hk	Colwell *et al* (1971)
Vietnam	Nghean Province	1991		5,414		5,414	As, Tr, Hk	Toan (1993)
Vietnam	Hatinh Province	1991		3,096		3,096	As, Tr, Hk	Toan (1993)
Vietnam	Thuathien-Hue Province	1991		6,202		6,202	As, Tr, Hk	Toan (1993)
Vietnam	Longan Province	1991		8,290		8,290	As, Tr, Hk	Toan (1993)
Vietnam	Nghe Tinh Province	1988		382		8,290	As, Tr, Hk	Kagei *et al* (1993)
Vietnam	Binh Tri Province	1988		876		8,290	As, Tr, Hk	Kagei *et al* (1993)
Vietnam	Long An Province	1988		790		8,290	As, Tr, Hk	Kagei *et al* (1993)
Vietnam	Thai Binh Province	1994	92		213[c]	305	Hk	Humphries *et al* (1997)
Vietnam	Nationwide	1995			5,016[c]	5,016	As, Tr, Hk	Anon (1995)

[a]Typical age ranges: Pre-school: 0-5 years; School-age: 5-14 years; Adults: 16+ years; [b]As = *Ascaris lumbricoides*; Tr = *Trichuris trichiura*; Hk = hookworm; [c]non-pregnant women surveyed

to investigate the ecological correlates of infection and predict the distribution of infection in unsampled areas on the basis on remotely sensed (RS) satellite environmental data.

The results of the regression analysis are shown in Table 2. For both *A. lumbricoides* and *T. trichiura*, maximum or minimum land surface temperature (LST) and mean or minimum Normalized Difference Vegetation Index (NDVI) were significant explanatory variables. For hookworm, no statistically significant models could be developed (data not shown). The resultant predictive maps are shown for *A. lumbricoides* and *T. trichiura* in Fig 2. For *A. lumbricoides*, it is suggested that prevalence is lowest in the central plains of Thailand and Myanmar, and highest in northern Vietnam, northern Myanmar, southeast Myanmar and southwest Cambodia (Fig 2a). For *T. trichiura*, prevalence is highest in northern Myanmar; northern Vietnam and Lao PDR have moderate prevalences; while the lowest prevalences occur in central Cambodia and central Thailand (Fig 2b).

A visual comparison of this map with observed prevalences (Fig 1a and 1b) shows many similar features and broad agreement. Perhaps of greatest importance for control programs is the ability to distinguish between provinces requiring mass treatment or not, based on WHO's mass treatment threshold of 50%, using the nationwide data for Vietnam. For *A. lumbricoides*, 90.4% of provinces were correctly predicted according to below and above 50% (k=0.806) and for *T. trichiura* 94.% of provinces were correctly predicted (k=0.381).

Estimates of numbers infected and target population for control

The model predictions presented above are of relevance to control programing as we can estimate the population size at risk of infection and identify priority areas for control (Table 3). Currently in Southeast Asia, we estimate that up to 74.7 million total individuals are infected with *A. lumbricoides* and 32.9 million are infected with *T. trichiura*. Using these estimates, it is possible to estimate the

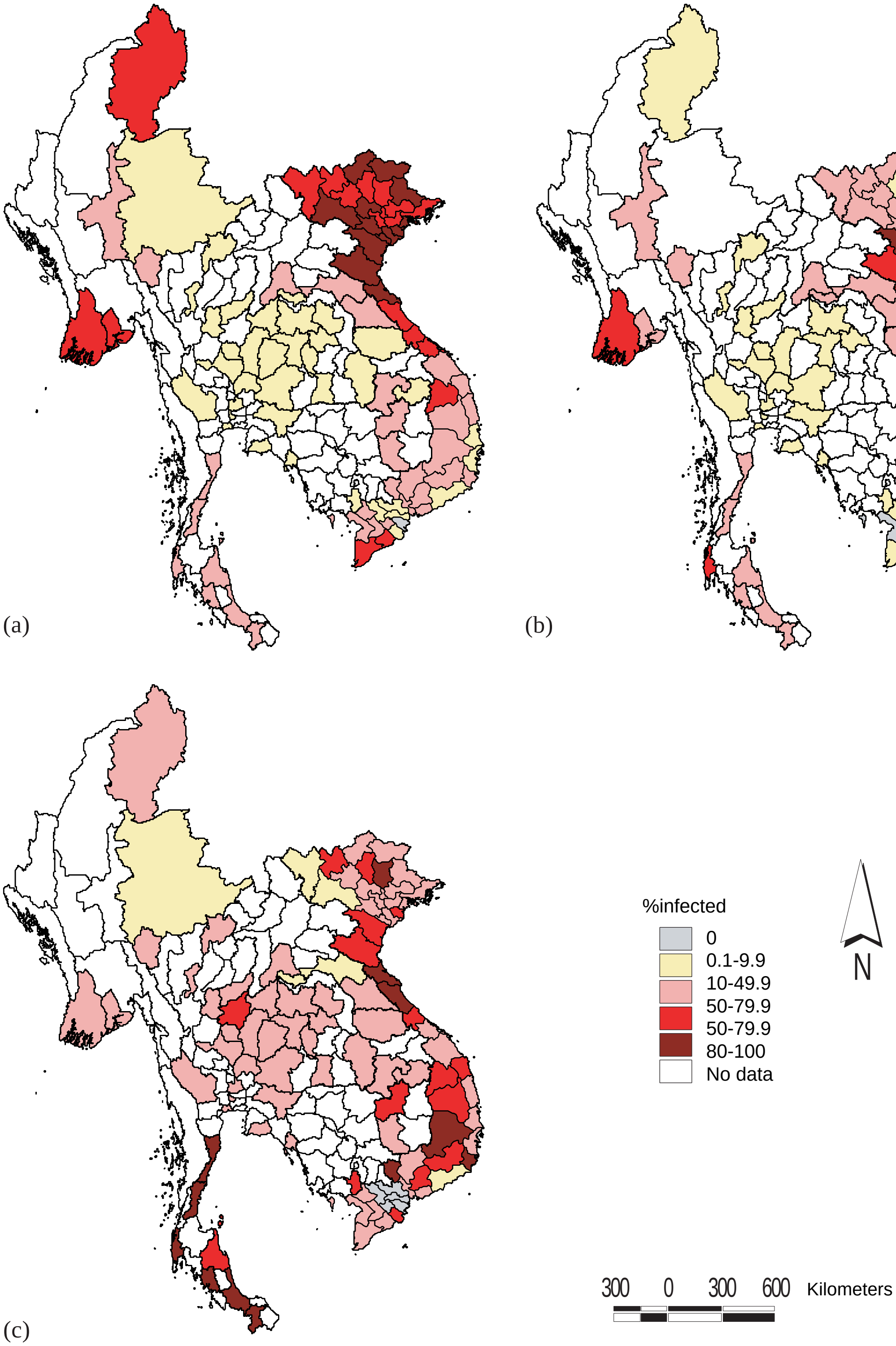

Fig 1–The distribution of (a) *A. lumbricoides*, (b) *T. trichiura* and (c) hookworm in Southeast Asia, as indicated by province-level estimates based on available survey data. White indicates those provinces where no relevant data were located at present.

target population for school-based albendazole treatment. Here, we have used a combined estimate of infection prediction for either *A. lumbricoides* or *T. trichiura*. To define whether a province would be a priority area for control, we have used a criteria based on average predicted prevalence being 50% or greater [WHO's criterion for mass treatment (WHO, 1995)] within a province. On this basis, we estimate that a total of 12.8 million school-age children in 35 of 175 provinces in the region would warrant mass treatment with albendazole. However, because there should be flexibility in the treatment thresholds to suit local needs, the analysis was re-run using a 20% prevalence threshold. On this basis, we estimate that 44.2 million school-age children in 134 provinces would receive mass treatment with albendazole.

Table 2
Regression coefficients describing the logistic regression models.

	Coefficient estimate	Residual deviance	p
A. lumbricoides			
Constant	72.081	1,943	
Maximum LST	-0.021	236	<0.0001
Minimum NDVI	-0.004	573	<0.0001
T. trichiura			
Constant	13.44	1,623	
Maximum LST	0.051	50	<0.0001
Minimum LST	-0.064	269	<0.0001
Mean NDVI	0.012	256	<0.0001

LST = Land surface temperature;
NDVI = Normalized difference vegetation index.

DISCUSSION

Using GIS, the present study enables a description of the distribution and prevalence of helminth infection in Southeast Asia using available data sources. However, it is clear that some caution is warranted in interpreting the present published data. Difference in survey methods and techniques and variation in the timings of surveys reduces the comparability of the data and the potential of the maps to represent infection prevalence precisely in every province. Nonetheless, the information included in the present database can help identify where current information is lacking and serve as a stimulus to collect new or additional data. Further suitable data may be available from local sources within-country, such as Ministries of Health or research institutes. Mapping filariasis in Vietnam for example, Meyrowitsch *et al* (1998) were able to identify detailed data from surveys conducted by the Institute of Malariology, Parasitology and Entomology. These experiences demonstrate the potential

Table 3
Summary estimates of predicted prevalence, numbers (total and school-age children) infected, and numbers warranting mass treatment using the 50% threshold.

	2002 population ('000s)	Estimated prevalence		Total number infected ('000s)		School-age children infected ('000s)		Total receiving treatment ('000s)[a]
		As[b]	Tr	As	Tr	As	Tr	
Cambodia	13,403	22.0	8.0	2,948	1,072	884	321	0 (498)
Lao PDR	5,778	35.8	21.3	2,068	1,230	552	328	99 (551)
Myanmar	50,033	28.8	17.6	14,409	8,805	4,322	2,641	509 (3,490)
Thailand	63,430	23.2	8.8	14,715	5,581	2,472	937	0 (1,859)
Vietnam	80,577	54.0	22.0	43,511	14,726	9,542	3,887	6,194 (9,419)
Total	213,221			77,654	34,417	17,774	8,117	6,802 (15,820)

[a] Number in brackets indicate numbers treatment based on 20% threshold.
[b] As = *Ascaris lumbricoides*; Tr = *Trichuris trichiura*.

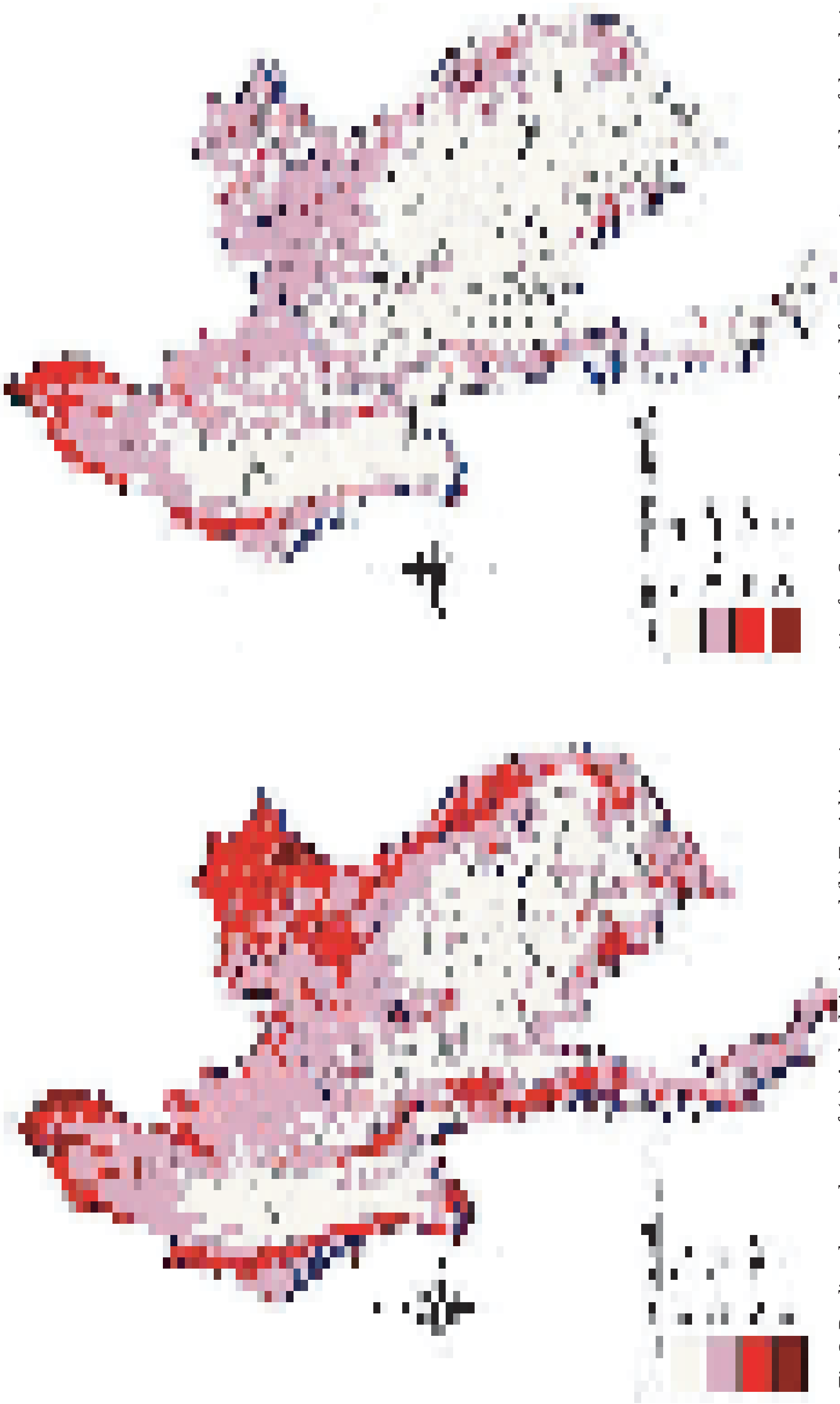

Fig 2–Predicted prevalence of (a) *A. lumbricoides* and (b) *T. trichiura* in communities for Southeast Asia, as derived from regression models of the relation between prevalence in Vietnam and environmental variables derived from remotely sensed satellite sensor data.

value of reports and surveys from the national literature, which can be used to investigate further the geographical distribution of helminths in Southeast Asia.

Given the paucity of available survey data, it proved necessary to generate predictions of the distribution of soil-transmitted helminths using remotely sensed (RS) satellite sensor environmental data. The use of RS data to predict infection patterns is justified on the basis that temperature and humidity are known to influence the development and survival of free-living transmission stages present in the environment [see Brooker and Michael (2000) for a recent review]. It follows therefore that these factors, and indirectly related environmental factors such as rainfall and altitude will influence transmission success, and observed patterns of infection. An important finding of the present study is the association of land surface temperature (LST) with observed distribution patterns. In Vietnam, the prevalence of *A. lumbricoides* and *T. trichiura* was <10% in areas where the maximum LST exceeded 37ºC, presumably because of the effects of heat and low humidity on the embryonation and survival of eggs. This finding is supported by experimental data: *T. trichiura* eggs take about 28 days to develop at 25ºC, 15 days at 30ºC and 13 days at 34ºC, and do not develop at all above 37ºC (Beer, 1976). The optimal temperature for the embryonation of *Ascaris* spp has been reported to be 31ºC (Seamster, 1950), and 38ºC is lethal (WHO, 1967). Further corroboration is provided by field data from the nationwide survey of China where temperature and humidity were shown to be associated with infection patterns (Xu *et al*, 1995; Lai and His, 1996).

There will, of course, be other factors influencing the distribution of soil-transmitted helminths such differences between rural and urban populations. The present results are suggested to represent rural populations. There will also be small-scale factors influencing infection patterns, including personal hygiene and behavior. For example, the use of human feces for fertilizer is quite common in Southeast Asia and contact with feces during agricultural work may provide a route of infection (Humphries *et al*, 1997; Peng *et al*, 1998). This practice may be an important influence on infection patterns, which arise because of differences in culture and farming patterns rather than differences in environmental variables. However, it is difficult to collect information on such behavior and other socio-economic indicators over large spatial scales. The advantage of RS data however is then provide information for the entire region at useful spatial resolution (8 x 8 km), useful for predicting the distribution of soil-transmitted helminths.

The ability to predict the distribution of infection has important consequences for planning and targeting control activities at the national level. Throughout the region, limited helminth control programs have been undertaken. In Thailand during the 1980s for example, control activities were concentrated on education and bi-annual mass treatment of school children in southern Thailand (Chongsuvivatwong *et* al, 1994). In 1989, the program was expanded to cover all ages in rural areas. However, it was suggested that the low efficacy of the drug used (mebendazole) and poor coverage meant that re-infection rapidly occurred, changing prevalence rates little. Other studies confirm the lack of change in prevalence rates in the last two decades, although there were reductions in intensity of infection (Anantaphruti *et al*, 2000). The high prevalence of soil-transmitted helminths in Cambodia and Lao PDR has resulted in the combined delivery of albendazole and praziquantel in school-age children in endemic areas for schistosomiasis (Urbani *et* al, 2002). More recently, albendazole treatment has been extended to other areas of Cambodia, totalling over 100,000 schoolchildren receiving annual treatment (Urbani, personal communication).

In an effort to promote parasite control in the region, the Asian Center of International Parasite Control (ACIPAC) has recently been established under the Hashimoto Initiative by the cooperation of Japan International Cooperation Agency (JICA). ACIPAC is based at

Mahidol University and the Department of Communicable Disease Control, Ministry of Public Health, Thailand as a training center for health personnel and related sectors in malaria and soil-transmitted helminthiasis (STH) control based on school health programs. The mission of ACIPAC is to encourage parasite control in the Greater Mekong Sub-Region (GMS: Cambodia, Lao PDR, Myanmar and Vietnam) countries with the expectation that at the end of the project the prevalence of parasitic infections in this region will be reduced to the level of a non-significant public health problem. The course of action includes: human resource development by international training courses for health managers of health and educational sectors, pilot projects in their countries, human/information network development with IT technology. These efforts are part of interagency initiatives undertaken by organizations such as UNICEF and WHO involved in parasite control. However, parasite control is meaningless without clean water and adequate sanitation facilities. Thus, it is also a realistic goal in most countries to ensure that all communities have access to clean water and sanitation. For example, UNICEF is currently working with ACIPAC for the promotion of school sanitation and hygiene. The application of GIS and remote sensing can assist in targeting these initiatives to areas in most need and thereby provide a useful planning tool.

In conclusion, the study has demonstrated the potential of a GIS/remote sensing modeling approach in Southeast Asia and has shown that the geographical distribution of *A. lumbricoides* and *T. trichiura* can potentially be predicted on the basis of environmental surrogates. This, in turn, can allow approximate estimates of the populations at risk of infection. We should caution however, that there are many areas which were poorly covered by prevalence surveys, and our regional models are entirely based on data derived from Vietnam. Future research, investigating the accuracy of the current predictions using new survey data will be crucial to better targeting control and is an area of on-going research. Nonetheless, the present study indicate the important role GIS and remote sensing are likely to play in current attempts to control soil-transmitted helminths in Southeast Asia and elsewhere in the world.

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