
Reviews/Analyses

New geographical approaches to control of some parasitic zoonoses

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The advent of new technology for geographical representation and spatial analysis of databases from different sectors offers a new approach to planning and managing the control of tropical diseases. This article reviews the geographical and intersectoral aspects of the epidemiology and control of African trypanosomiasis, cutaneous and visceral leishmaniasis, Chagas disease, schistosomiasis, and foodborne trematode infections. The focal nature of their transmission, increasing recognition of the importance of animal reservoirs, and the need to understand environmental factors influencing their distribution are common to all these diseases. Geographical information systems (GIS) open a completely new perspective for intersectoral collaboration in adapting new technology to promote control of these diseases.

Introduction

Geographical approaches, particularly geographical information systems (GIS), provide common ground for dialogue between zoologists, veterinarians and medical public health workers. As a result, there is now increasing awareness of the role of animals in the epidemiology of human "emerging" infections (5), and the control of tropical diseases is gradually involving other sectors besides traditional public health services.

GIS is a computer-based technology for input, storage, analysis and display of spatial data (19). It permits cross-sectional display and analysis of multiple databases using real geographical coordinates to a specific scale, i.e., rainfall, soil type, soil humidity, health services infrastructure, disease vectors, and infection or disease in animals and people. This relatively new analytical tool in the field of epidemiology facilitates the collaboration of different sectors

and can be flexibly adapted to the needs of the endemic countries. The effective integration of new technology such as GIS is done methodically in a step-by-step fashion. For control of tropical diseases all applications begin at the periphery. If the data generated at the periphery have not been reliably collected and checked, no amount of sophisticated technology at the central level can improve them. Furthermore, GIS analyses to determine causal relations are estimates or approximations to support or refute hypotheses, and their conclusions should be confirmed by field epidemiological studies.

Appropriate use of new geographical approaches will depend on (1) proven benefit from older geographical approaches in control, (2) a clear priority for the sequence of introduction of databases, and (3) scientifically sound hypotheses. If these three criteria are not fulfilled, the new geographical approaches may become junkyards or graveyards of databases.

This review describes the evolution of geographical approaches and methodology as applied to understanding the epidemiology of parasitic diseases with animal intermediate hosts. It does not include the use of remote sensing and satellite image data in relation to vector-borne diseases, which other authors have recently described (13, 16, 25) and which require sophisticated technologies (both hardware and software) to analyse the data input. Moreover, remote sensing data are managed and analysed as one of the databases in a GIS.

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Geographical approaches

This article does not cover the history of geographical approaches for controlling tropical diseases. Their origins have been variously interpreted, e.g., maps of the drainage operations of the Pontine swamps in ancient Rome to eliminate malaria—long before the link between the parasite and the mosquito could be imagined, or the map of cholera cases in London in 1833–34 which pinpointed the Broad Street public pump as a point source of infection.

In all operational tropical disease programmes the necessity of maintaining a geographical approach is recognized. In the field, simple maps bring out information which can easily be interpreted and used in management of control activities. In the 1960s, for example, sketch maps of malaria endemic areas served as the basis for all operations, surveillance and monitoring in attempts at global malaria eradication. Simple sketch maps of endemic areas have been used so extensively in national control programmes under the Ministry of Health that the entire northeast of Brazil has been literally mapped, by household, on A4 sheets to define malaria or smallpox surveillance routes, or the distributions of Chagas disease, yellow fever, leishmaniasis and schistosomiasis.

The advent of technologies for geographical representation of epidemiological data presents new opportunities and challenges for the health sector. One of the principal challenges is to establish a working dialogue with other sectors. Geography is not the domain of any one sector. Its very nature surpasses the territoriality of any one field of science. While computer-assisted cartography and geographical information systems have expanded the potential, if not the ease of geographical approaches, we are confronted by constraints such as lack of map boundary data and the intrinsic unreliability of other databases. The standard atlases of disease distribution have always recognized this fact (9). More recently this has been the cause of a dramatic appeal to correct the absence of adequate map databases (11).

African trypanosomiasis

The history of the control of African trypanosomiasis stands out as a model on the use of geographical approaches linking veterinary and human public health objectives and operations. During the colonial period in Africa, mapping the distribution of the geographical limits of tsetse flies, animal reservoirs, and human disease preceded the control efforts. Since 1954, FAO/WHO collaboration in this area has confirmed the intrinsic necessity of a geographical approach to control.

The parasites causing human African trypanosomiasis, *Trypanosoma brucei gambiense* and *T.b.*

rhodesiense, are transmitted by *Glossina* (tsetse flies). Both parasites infect domestic and wild mammals. The disease due to *T.b. gambiense* occurs in 27 countries of West and Central Africa and is mainly transmitted between infected persons. The role of animals as a reservoir and in the epidemiology of this form of the disease is ill defined. On the other hand, disease due to *T.b. rhodesiense* occurs in 10 countries of East and South-East Africa and the disease is clearly zoonotic. Wild and domestic animals play an important role in foci for disease maintenance and resurgence (32).

Transmission of sleeping sickness is focal, even within the limits of an endemic area so that transmission and risk of infection are not homogeneous. Only 10 of the 31 known species and subspecies of *Glossina* are incriminated as vectors in sleeping sickness transmission. Transmission is predicated on the presence, type and behaviour of vectors and is closely linked to the environment (i.e., minor hydrographical features play a major role in determining transmission sites). Peoples' attitudes and habits are also major factors in transmission occurrence and intensity. In general, risk areas and populations at risk are poorly defined. In most endemic countries, large geographical areas have been designated as being "high risk" for transmission, while in reality the actual areas at risk of transmission are focal and separated, sometimes by large distances.

Within a geographical approach to sleeping sickness, the distribution of infected persons, infected animals, tsetse flies (species type as well), and of various environmental factors such as water bodies, forests, roads, villages, plantations, etc. are needed. To implement or improve control approaches, identification of cross-sectional areas where several complementary or limiting factors coexist may be useful. Circumscription of the sites to be brought under surveillance, where control is needed, is the first step in a long-term control strategy—not unlike the GIS-based methodology proposed in Guatemala for onchocerciasis (24).

The operational aspects of control also have to be considered in the application of geographical methodologies. In the course of passive surveillance (fixed post-systematic surveillance), the identification of the origin of patients with African trypanosomiasis may play the role of an "early warning device" for the resumption of transmission and the identification of the geographical area at risk of an epidemic. The usefulness of the data will depend on the extent to which they have been accurately recorded and integrated into a GIS-based file and analysed immediately rather than accumulated and analysed in an aggregate fashion. Certainly data from active surveillance should have carefully defined sur-

vey areas on a GIS map and the database records should include the origin, number of patients, treatment and secondary reactions, date of examination, patients' follow-up including date, location, test results, physical condition, and relevant medical, environmental and social information.

Vector control is generally considered a crucial component of all operational programmes. The databases already available are usually very extensive and detailed. Integration of existing databases can be time-consuming and may not be necessary to address the current programme needs. All data collected and integrated into GIS should optimize the available resources to achieve and sustain control of sleeping sickness.

An environmental study in the Vavoua focus in Daloa prefecture, Côte d'Ivoire, has opened a new area of GIS analysis to support the control of African trypanosomiasis.^a This study has shown that there is a direct correlation between the risk of *Trypanosoma* infection and the agricultural cultivation methods of certain "socially open" groups (communities comprised of different ethnic groups, e.g., exogenous tribes such as Mossi or Dioula and endogenous tribes such as Gouro or Baoulé), compared with the agricultural methods of "socially closed" communities of monolithic tribes. Landscape contrast due to the difference in types and methods of cultivation can be observed in the field. Correlation between agricultural habits and disease distribution was first noticed by comparing static maps. Studies are now being implemented to combine remote sensing and GIS to allow for the quick assessment of risk for rapid preventive intervention (vector trapping) and for case detection (mobile surveys or in fixed centres).

A detailed geographical analysis of the environment—vegetation/vector distribution/human population and infection in Nola Biolo area of the Nola prefecture of the Central Africa Republic—has shown that *G. palpalis palpalis* tsetse flies were the main vectors in the coffee plantations and *G. fuscipes fuscipes* in the manioc fields and at bathing sites.^b Operationally this was important since there is a short geographical overlap of the ranges of the tsetse flies and the trapping methodology must be adapted for each species.

In a large-scale control programme in southern Uganda, the distribution of tsetse fly traps was deter-

mined by the geographical origin of sick persons.^c Exhaustive trap placement throughout the entire endemic area was not feasible owing to lack of logistics and limited financial resources. Thus, detailed maps of the patient's origins were required for permanent adjustment of planning and implementing control. In northern Uganda, population movements related to civil unrest and refugees were of strategic importance since the majority of infected persons originated from Sudan.

Before user-friendly GIS software for the personal computer became readily available, an operational plan was completed to define the peripheral health care system in the Moundou prefecture of Chad.^d Subsequently, an attempt was made to integrate control of African trypanosomiasis (*T. brucei gambiense*) by superimposing a series of maps with the health centres having a catchment area of 10 000 persons and accessible within 30 km. Using static maps it was difficult to adjust the catchment areas to correspond to the population density and distance to the health centres. It was found that the major limitation in using static maps was the need for constant recalculation of the data, even though the disaggregated or discriminant data on habitations, river basin boundaries, and agricultural areas were available and were represented on the static maps. Today a similar type of operational GIS analysis could be implemented within weeks and kept up-to-date.

Using sequential geographical mapping, Simarro et al. (28) showed that foci in three villages were the origin of transmission of *T. gambiense* in the larger endemic area of Luba district of the island of Bioco in Equatorial Guinea. Cases on the island occurred mainly in proximity to these three foci, each limited by altitude and surrounding vegetation. From a historical review of the geographical distribution of human infection, they concluded that if early preventive action had been undertaken in the areas of the appearance of the first cases, the extension of the foci could have been avoided. It is now possible to integrate data derived from health services and specific surveys into a GIS which would establish the potential limits of a focus of transmission. Thus, the preventive control measures could effectively be targeted to the population at risk.

^a Laveissiere C et al. *Les communautés rurales et la lutte contre la maladie du sommeil en forêt de Côte d'Ivoire*. Unpublished document, WHO/TRY/94.1, 1994.

^b Kounda Gboubi J-C. *Les glossines de la région de Nola. Espèces et répartition. Relation avec la trypanosomiase humaine et possibilités de lutte*. Thesis for diploma in Public Health, Université Marien N'Gouabi, Bangui, 1990.

^c C. Lancien, personal communication in report of the National Sleeping Sickness Control Programme, Center of Control of Trypanosomiasis, Vector Control Project in Busoga.

^d Tobyo AS, Bouchet B. i) *Programme de contrôle de la trypanosomiase humaine en République du Tchad*. ii) *Propositions du Comité-Santé pour la mise en place du plan de couverture sanitaire des districts du Logone Occidental*. Unpublished documents, Projet de coopération Franco-Tchadienne, Convention No. 356/C/89, 1991.

Chagas disease

Chagas disease or American trypanosomiasis affects up to 18 million persons in 17 countries of the Western Hemisphere (34). Since its discovery in 1909 by Carlos Chagas, the complex interaction between *Trypanosoma cruzi* in the arthropod reduviid vector and in wild and domestic animals and man has been a focus of research and been taken into account by all control strategies. The zootic cycle of *T. cruzi* extends far beyond the endemic areas of human infections; however, in areas where the disease is primarily zootic, the level of socioeconomic development has been extensive and contact of people with both the reduviid vector and reservoirs is random. In Latin America, the domestic cycle of the disease is rapidly disappearing in the face of extensive control efforts and public recognition of the danger of the presence of the bug in households (34).

Prospective cross-discipline studies to assess the interrelationship between the sylvatic, peridomestic and domestic dynamics of *T. cruzi* transmission are few. Using isoenzyme techniques, it was possible to identify and describe the distribution of three different zymodemes in one defined geographical area in Castro Alves, Brazil (3). The dynamics and spread of one reduviid vector, *Triatoma infestans*, from south Brazil into the north along the pilgrimage and migration routes through the interior has been documented (2).

The potential for application of new geographical approaches to assist management and control of Chagas disease is now accentuated by the increase in transmission in urban and periurban areas and the extensive transmission through blood products (21). Although the quality of data collection is improving with the commitment of the Southern Cone countries towards eradication of Chagas disease, accurate definition of the geographical distribution and prevalence are still lacking.

Leishmaniasis

The complex of diseases caused by *Leishmania* affect more than 12 million persons in 88 countries. Cutaneous leishmaniasis due to *Leishmania major* affects more than 500 000 persons in 35 countries, principally in the Eastern Mediterranean region. In developing a geographical perspective of these diseases, it is noteworthy that there is no person-to-person transmission of leishmaniasis in the Western Hemisphere. On the other hand, *Leishmania major* which causes cutaneous leishmaniasis in the Eastern Mediterranean region involves rodent reservoirs (zoonotic), while *L. donovani* causing kala-azar in Bangladesh, India, Nepal, and East Africa and *L. tropica* causing cutaneous leishmaniasis in urban and periurban areas are transmitted from person to person by *Phlebotomus* (sandfly) species (33).

Natural population fluctuations of rodents are directly linked to the epidemics of cutaneous leishmaniasis. Migrations of nonimmune persons into endemic areas are associated with epidemics of cutaneous leishmaniasis or visceral leishmaniasis (kala-azar) spreading from person to person. Four examples in different geographical areas are presented which give insights into how management and monitoring of control require a geographical approach.

Since 1983 in Tunisia more than 36 000 persons have been diagnosed to have cutaneous leishmaniasis which is now recognized as a national health priority (5). The majority (65%) of these cases have been reported within the governorate of Sidi Bouzid in northern Tunisia and many of those infected come from the urban and periurban area of the capital of the governorate. This urban epidemic is linked to the increasing populations of the sand rat (*Psammomys obeus*), the main mammalian animal reservoir, and the distribution of *Atriplex* sp., a chenopode which is the sole food source for *Psammomys*. The other important animal reservoir is the gerbil (*Meriones shawi*), whose habitat in this and other endemic areas does not overlap with *Psammomys*.

The control of cutaneous leishmaniasis in Tunisia demands a sound geographical approach. The actual and potential habitats of *Psammomys* are strictly defined by the distribution of the chenopode, which is mechanically destroyed and replaced by planting *Acacia cyanophylla*. *Meriones* populations are limited by wheat/oil baits soaked in 3% zinc phosphate. Thus, the geographical extent of animal habitats will define both the zone of risk of human infection and the zone of intervention for control.

In Ethiopia, long-standing foci of cutaneous leishmaniasis (locally known as "bolho") due to *L. aethiopia* are found in the basalt rock hills at an altitude of 1500–2700 metres above sea level. Annual rainfall averages 400–600 mm. Each family lives in a self-contained compound with dense banana and coffee plantations. Most of the houses are grass-thatched huts. After careful mapping and census of the relatively isolated village of Ocholo, surrounded by steep cliffs, a house-to-house survey was completed (20). The prevalence of active lesions was 3.9%, and 34.3% of the 3200 persons living in 900 houses had scarring due to leishmaniasis. The high level of transmission was explained by the particularly close proximity between the houses, the caves where abundant colonies of hyrax (*Procapra* sp.), the proven animal reservoir, live together with the proven sandfly vector (*Phlebotomus pedifer*). Within this village, the disease was heterogenous: localized cutaneous, diffuse cutaneous and mucocutaneous leishmaniasis were observed. In this situation, not unlike most, it is necessary to define the dispersal range of

the sandfly, i.e., the distance at which the mean number of infected females is maximum, the population dynamics of the mammalian host, the distribution of the sandfly habitats (caves, burrows), and the location of houses with infected persons to understand the spatial correlates which are useful for intervention.

In Sudan, visceral leishmaniasis is apparently directly linked to the traditional livestock grazing patterns. Transmission of visceral leishmaniasis occurs seasonally in the acacia forests of the south bordering the rivers. The cattle are brought there in the dry season from the central and western parts of the country. The recent epidemics have been linked to refugee movements due to civil unrest. Utilization of GIS has been proposed as part of the planning and implementation of control in this area.⁶ It is noteworthy that in this area of the Rift Valley, extensive geo-referenced data as well as remote sensing images have been used to analyse earthquake patterns (12). The initial geographical analysis has indicated that the only feasible control approach is the use of individual protection among the migrants. Trials with impregnated bednets are postponed due to war.

Visceral leishmaniasis had not been reported from the state of Rio de Janeiro until 1977; by 1990, 59 cases had been reported (17). The peak incidence occurred in 1981. The high-risk areas were defined by simple mapping of cases. The majority of cases were in proximity to the Gericinio and Pedra Branca massifs. To test retrospectively the hypothesis that deforestation was a major factor in the changing epidemiology, the remote sensing data (Landstat MSS) from the Rio de Janeiro Municipal Secretariat for General Planning and Coordinations were reviewed in an attempt to understand the rates of deforestation in that state. It is striking that in areas over 100 m altitude, the rate of deforestation was over 10% between 1972 and 1978, in spite of extensive legislation against deforestation and promotion of conservation of forest cover at above 100 metres. Furthermore, within the state, several long-distance electric powerlines were constructed with accompanying deforestation linking the endemic areas of kala-azar.

The geographical analyses have not provided causal links between environmental and epidemiological observations. On the other hand, they have demonstrated the effectiveness of standard control measures which focused on geographical principals,

e.g., canine serological surveys, elimination of infected and seropositive dogs, and spraying of all households of infected persons and a 100-metre radius around the households. Currently, the rates of seropositive dogs has decreased significantly (from 4.3–12.7% to 0.4–1.8%) in different areas.

With the rapid urbanization in most countries endemic for leishmaniasis, GIS offers a new tool for control. It appears that national authorities are increasingly aware of the usefulness of GIS for urban planning and monitoring growth. Monitoring of disease patterns and intervention can be enhanced by integration of health/disease variables into the urban GIS systems.

Schistosomiasis

Schistosomiasis affects more than 200 million persons in a population of 600 million in 74 developing countries. The epidemiology of schistosomiasis is rapidly changing and new geographical approaches are required to promote prevention and control. Four situations where schistosomiasis transmission is increasingly linked with infection in animals have now been documented: urban/periurban, irrigation systems, delta areas related to dam construction, and civil strife/war (35).

Aside from the role of people as the major reservoirs of infection, future epidemiological studies and control programmes should give attention to the role of other mammals in maintaining transmission. No less than 38 mammals have been found to be naturally infected by *S. mansoni* (26). A review of the situation in Brazil showed that at least 15 species of mammals, mostly rodents, were naturally infected (23). Most importantly, it was noted that the reports of mammalian infection are increasing and it appeared that in urban and periurban areas the epidemiology of human infection may be linked to that of these rodents in the northeast of Brazil.

Since 1962, natural *S. mansoni* infections have been found in cattle (*Bos taurus*) in Brazil, Sudan and Venezuela (6). However, these anecdotal reports have never been followed up with detailed studies in endemic areas with dense cattle populations. Although experimental infections with *S. haematobium* have been achieved in large primates, and most recently in mice (14), there is no published evidence of natural infection in other mammals. Likewise, over 30 mammals have been found infected with *S. japonicum* and recent evidence suggests that the epidemiology of human infection is linked to the distribution and prevalence among coinciding animal populations.

The changing trend towards urbanization of schistosomiasis in the northeast of Brazil and in

⁶ Connor SJ, Thomson MC. Towards an understanding of the 'Eco-epidemiology' underlying the current leishmaniasis epidemic in southern Sudan: the role of remote sensing and geographical information systems in the decision support. Liverpool School of Tropical Medicine, Consultancy report to MSF-Holland. March 1994.

Africa has been reviewed (4, 21). Further reports from Guider in Cameroon (31), Bata in Equatorial Guinea (27), and Brazzaville in Congo (1) confirm that this phenomenon is now widespread and involves all species of human *Schistosoma*.

In three areas of the world a change in the distribution of the type of schistosomiasis has occurred in the past 20 years: in the Nile delta of lower Egypt, in the Volta delta of Ghana, and in the deltas of the rivers of southwest Cameroon. In all these areas the predominant type of schistosomiasis has shifted from *S. haematobium* to *S. mansoni*, and possibly in the Cameroon also the spread of *S. intercalatum*. All these areas are downstream from major dams which have altered the ecology of their respective deltas.

The most recent dramatic example is in Senegal. The first dam on the Senegal river was constructed in Taouey at Richard Toll in 1948. This retarded the seasonal flood from backflowing into Lake Guiers. It permitted irrigation of 6000 hectares for rice cultivation and was subsequently changed to sugar cane production. Subsequently, the Diama dam, a gate structure dam with an embankment dam on the Senegal River at St Louis, was completed in August 1986, blocking salt water intrusion during the dry season and creating a reservoir for irrigation and industrial installations. Surveillance through the laboratory of the health centre in Richard Toll began in May 1987. The first cases of *S. mansoni* infection were reported 18 months after the dam became operational in early 1988. In the last trimester of 1989, 71.5% of 2086 passive stool examinations were positive (30). The role of increased rodent populations (*Arvicanthus niloticus*, *Mastomys huberti* and *M. erythroleucus*), with focally high levels of infection in this area, may have an important role in changing the pattern of the transmission (10).

Strife and unrest have caused the movement of people to an extent never before imagined. The situation is so dynamic and changing that the effect on the introduction, spread, or aggravation of schistosomiasis is difficult to monitor. In Somalia, *S. mansoni* is now endemic in the areas where Ethiopian refugees have been present. In Laos and Cambodia, the

impact of refugee movements on transmission must still be determined, but *S. mekongi* has been diagnosed frequently in some Thailand refugee centres.

The potential for predictive modelling of schistosomiasis is an attractive application of GIS. By layering different maps of soil type, soil humidity and hydrology, Nihei et al. (22) successfully predicted the habitats of *Oncomelania* in Japan. Subsequently, remote sensing environmental data were used to classify potential levels of transmission of schistosomiasis in the Philippines (7, 8), but this study was not supported by ground proofing.

Foodborne trematode infections

Foodborne trematode infections offer new and exciting opportunities for intersectoral collaboration through use of new geographical approaches. Globally, more than 40 million persons are infected with some type of foodborne trematode; the extent of the problem is indicated in Table 1. These diseases represent a new global challenge for food safety and parasitic disease control programmes.

The WHO database is integrated into a GIS using MapInfo (from MapInfo Corporation) with, for the present, first-order (NUTS 1) boundary files for countries (18). As the national programmes develop it is anticipated to have up to fourth-order boundaries at the smallest administrative unit.

Aquaculture is rapidly expanding and all estimates suggest that this expansion will continue and accelerate into the next century. GIS applications in aquaculture are extensive (19). As yet there is no linkage with the public health problems related to wastewater use and risk of infectious and parasitic diseases. On the other hand, the economic imperative of freshwater fish production will increase internal and foreign markets. It is foreseen that the Micro-computer-based Commodity Analysis and Information System (MICAS) developed by UNCTAD¹ to

¹ Special UNCTAD Unit of Commodity Analysis and Information System. Commodity Division, UNCTAD, Palais des Nations, 1211 Geneva 10, Switzerland.

Table 1: Global distribution of foodborne trematode infections

Disease/food item	Parasite	No. of countries	Population at risk (x10 ⁶)	Persons infected (x10 ⁶)
Clonorchiasis/freshwater fish	<i>Clonorchis sinensis</i>	9	290	7
Opisthorchiasis/freshwater fish	<i>Opisthorchis felineus</i>	2	14	1.5
	<i>Opisthorchis viverrini</i>	2	50	9
Paragonimiasis/freshwater crab	<i>Paragonimus</i> species	39	195	21
Fascioliasis/watercress	<i>Fasciola hepatica</i>	61	180	2.4
	<i>F. gigantica</i>			

assist investment and diversification will include fish and fish products incorporating FAO databases in a GIS.

The epidemiology of human fascioliasis has undergone dramatic revision in the last five years. Its extent is far greater in the Andean altiplano from Bolivia to Ecuador, in the Nile delta, and in the Caspian region of the Islamic Republic of Iran than was previously recognized. The usefulness of GIS in integrating remote sensing data has been demonstrated by Malone et al. (16) who assessed the epidemiology of animal fascioliasis in Louisiana (USA). As yet, we do not have applications in areas where human disease has been reported.

Since the closure of the Aswan High Dam in 1964, there has been a rapid geological evolution of the Nile delta (29). The geological analysis of these changes has incorporated remote sensing data. In view of the increasing prevalence of human fascioliasis in the Nile delta, a GIS-based analysis seems opportune.

Discussion

There are many common geographical issues among the control approaches against parasitic diseases reviewed in this paper. These issues may be classified into two major types: those inherent to the disease (epidemiological, environmental or biomedical), and those relating to control activities (human resources, organization, coordination, etc.).

Schistosomiasis, trypanosomiasis and other parasitic diseases occur in relation to common environmental denominators. Understanding of the first group of issues is necessary to plan for control. A single control action, based on appropriate epidemiological, environmental and biomedical interpretation, could considerably reduce transmission of two diseases. Moreover, additional actions could totally prevent or even eliminate other diseases under certain conditions.

The distribution of health services is of common interest to all control programmes. Control activities will eventually, if not from the outset, be part of the local health services. Thus the spatial relations between disease distribution and health services should be an essential part of any GIS for control of tropical diseases. Control action, mostly managerial, involves mainly the second set of issues. It is possible to pinpoint where changes in staffing and infrastructure can be useful to achieve better delivery of control (diagnosis and treatment, environmental management) and maintenance of control.

The focal nature of the distribution, although not unique to parasitic diseases, is a characteristic of all

diseases in this review. Thus the extent to which a geographical approach can benefit implementation, monitoring and maintenance of control operations will depend on the level of discrimination of the data collected and their reliability. Ultimately a control operation must reliably determine if it can be stopped without risk of recurrence or reintroduction. For the first time GIS affords a practical way of determining overlap of "focality" and of making this information readily available for programme planning and execution, both centrally and at the periphery of endemic countries.

Aside from the common issues, new problems will become evident as GIS attracts more attention.

Today single disease databases are rare; where they exist they are incomplete. While an enormous amount of information has been and is being collected in the peripheral health services, it is usually not compiled in a format suitable for common databases. Usually the original data are analysed at a peripheral health unit and synthesized into a report where they become so aggregated that they are difficult to interpret or integrate into a database. Furthermore, in the process of aggregation, any geo-referenced data will become obscured. This methodology is not due to the technical impossibility to obtain the required information or to develop a proper database, but due to the lack of current management guidelines of epidemiological reporting of tropical diseases in health care systems of endemic countries. Exceptionally, only certain diseases may be specifically reported. In general, the broad classifications of "febrile illness" or "parasitic disease" may mask the actual cause.

Many tropical diseases coexist in the same geographical area. Yet the creation of common disease databases continues to be a chimera. From a distance or intuitively such common databases seem feasible, but experience dictates otherwise. For example, the separate organizational and administrative structure in the Ministries of Health of endemic countries limit any initiative to create common databases, let alone to share scarce resources.

Before databases are input into GIS, the final output objectives should be discussed and clearly defined. In the early stage of implementation it is not uncommon to create databases without forethought as to the expected outcome. GIS software is capable of storage of numerous and extensive databases. Thus, a GIS can potentially calculate an enormous number of variables which might not all be relevant to planning or monitoring of tropical diseases. GIS does not eliminate misinterpretation of the data, so sound epidemiological understanding and mapping for comprehension are prerequisites. A map prepared with inappropriate variables (i.e., using absolute

Table 2: Geographical databases used in the control and monitoring of some parasitic diseases

	African trypanosomiasis	Chagas disease	Leishmaniasis	Schistosomiasis	Foodborne trematodes
Demography	+++ ^a	+++	+++	+++	+++
Geology	+	+	+	+	+
Hydrology	++			+++	+++
Temperature	+	+	+	+	+
Altitude	+	+	++	+	+
Health services	+++	+++	+++	+++	+++
Schools			+	+++	
Roads	+++	+++	+++	+++	+++
Crops/agriculture	+++			++	+++
Dams			+	+++	
Vectors:					
Tsetse	++				
Reduviid		++			
Sandfly			++		
Snails				++	++
Hosts:					
Wild mammals	+	++	++	+	
Domestic animals	++	+			+++
Eating raw freshwater fish/aquaculture					+
Eating raw freshwater crabs					+
Watercress (<i>Fasciola</i> only)					+

^a + = useful, if available; ++ = needed; +++ = essential.

values without denominators instead of prevalence), or which attempts to display too many or unselected variables, will be detrimental to communicating the intended information.

At this stage in time, GIS presents an unforeseen difficulty which may be transitory, but is nevertheless very real—the need for reliable map boundary files. We believe that electronic map boundary files are available from national or international sources. The problem is where to find them. Map boundary files which have been approved for national government programmes are usually available through the government agency concerned with maintaining the records of national territory. In principle, we believe that any statement on the lack of map boundary files reflects a limitation of the search rather than the absence of such files. Thus, it is not necessary to digitize static maps *de novo* except for specific local programme requirements. Various WHO programmes are now exploring GIS applications and the first hurdle, if not obstacle, is the acquisition of boundary files. An inventory of public domain boundary files, which can be easily accessed and used in specific GIS software, has been prepared which will be revised periodically.⁹

In spite of these current limitations and “growing pains”, GIS offers new and attractive opportunities.

While the potential uses of GIS for predictive modelling are attractive research objectives, the control of tropical diseases requires simple and robust applications to support current operations. The complex epidemiology of parasitic infections involving environment, animals and people must therefore be reduced to simplified data collection and analysis which can be carried out in the endemic areas.

The new geographical approaches provide a focus for different sectors to converge as equal partners—a good example of intersectoral cooperation. However, the public health sector is both chronologically and technically behind other sectors in the functional application of GIS. Rapid progress in GIS software development and applications in the other sectors can certainly benefit the integration of health data into the ongoing national GIS.

⁹ Nuttall I. Inventory of administrative boundary files for computerized geographical applications. Unpublished document, WHO/SCHISTO/94.109, 1994.

All development sectors are confronted with decentralization and the question of sustainable development. The global trend of governments and the public as well as private sectors is towards the periphery, whether it be in marketing or health care delivery. This changes the strategy for control of tropical diseases which has traditionally been carried out in campaign fashion under the aegis of national quasi-military public health organizations. The costs of logistics and the limitation of personnel have been enormous—and are unsustainable. As endemic countries struggle to implement control without foreign aid or interference, the existing health systems and staff are being designated to undertake control measures. GIS offers a new and practical methodology to define the spatial relationships between the health care system, disease distribution, and the factors influencing the distribution. Moreover, as its analytical potential is exploited, GIS can provide allocation options for decreasing health budgets and reducing the number of staff, which might not be possible in any other way.

At present, most estimates of the distribution, prevalence and incidence of parasitic diseases are based on assumptions of the homogeneity of distribution in large administrative units. The current epidemiological methodology is unable to utilize or synthesize the discriminative data from small geographical units (villages or individual households) in a statistically acceptable manner, which can be done by GIS. If extensively implemented to promote planning and monitoring of control of tropical diseases, GIS could contribute to a complete revision of our current understanding of the distribution and prevalence of tropical diseases.

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Résumé

Nouvelles approches géographiques de la lutte contre certaines zoonoses parasitaires

Les approches géographiques, en particulier les systèmes d'information géographique (GIS) constituent une base de dialogue entre différents secteurs, rassemblant des zoologistes, des vétérinaires

et des agents de santé publique. La reconnaissance de plus en plus grande du rôle des animaux dans l'épidémiologie des maladies humaines entre dans le cadre du phénomène des infections "émergentes". Outil analytique relativement nouveau dans le domaine de l'épidémiologie, le GIS consiste en une technologie informatique de saisie, de stockage, d'analyse et de visualisation de données spatiales. L'intégration d'une nouvelle technologie comme le GIS se fait d'une façon méthodique, étape par étape.

L'utilisation appropriée des nouvelles approches géographiques reposera sur: 1) l'intérêt prouvé de l'utilisation des anciennes approches géographiques dans la lutte contre la maladie; 2) une priorité clairement établie pour la séquence d'introduction des bases de données; et 3) des hypothèses scientifiquement fondées.

L'historique de la lutte contre la trypanosomiase africaine constitue un remarquable modèle de l'utilisation des approches géographiques pour relier les objectifs et les opérations de santé publique humaine et vétérinaire. La transmission de la maladie du sommeil est focale, même à l'intérieur d'une zone d'endémie, de sorte que la transmission et le risque d'infection ne sont pas homogènes sur le plan géographique. Le potentiel d'application des nouvelles approches géographiques à la prise en charge de la maladie de Chagas et aux activités de lutte est actuellement renforcé par l'augmentation de la transmission dans les zones urbaines et périurbaines et par la transmission de plus en plus fréquente par le biais de produits sanguins.

Etant donné l'urbanisation rapide dans la plupart des pays où la leishmaniose est endémique, le GIS constitue un nouvel outil de lutte. Les analyses géographiques n'ont pas démontré de lien causal entre les observations environnementales et épidémiologiques sur la leishmaniose. En revanche, l'efficacité de mesures de lutte standard axées sur des considérations géographiques a été démontrée.

La possibilité d'une modélisation prédictive de la schistosomiase constitue une des applications intéressantes du GIS. En superposant différentes cartes représentant les types de sol, l'humidité du sol et l'hydrologie, il a été possible de prédire les habitats du gastéropode hôte intermédiaire au Japon. Des données environnementales obtenues par télédétection ont été utilisées pour classer les niveaux potentiels de transmission de la schistosomiase aux Philippines. Les infestations à trématodes transmises par les aliments offrent de nouvelles occasions intéressantes de collaboration intersectorielle grâce aux nouvelles approches géographiques.

Les aspects géographiques communs aux approches de lutte utilisées contre les maladies parasitaires peuvent être classés en deux grands types: les questions inhérentes à la maladie (épidémiologiques, environnementales ou biomédicales), et les questions relatives aux activités de lutte (ressources humaines, organisation, coordination etc.). Outre ces questions, de nouveaux problèmes apparaîtront à mesure de l'utilisation du GIS. Actuellement, les bases de données séparées sur les maladies sont rares, et lorsqu'elles existent elles sont incomplètes. De nombreuses maladies tropicales coexistent dans la même région géographique, mais la création de bases de données communes sur les maladies se heurte à la séparation des structures organisationnelles et administratives au sein des ministères de la santé des pays d'endémie.

Malgré ces limitations actuelles et ces "doux de croissance", le GIS offre des perspectives intéressantes. Mais tandis que les utilisations potentielles du GIS pour la modélisation prédictive constituent des objectifs de recherche intéressants, la lutte contre les maladies tropicales exige des applications simples et robustes à l'appui des opérations actuelles. Les nouvelles approches géographiques constituent le point de convergence des différents secteurs en tant que partenaires égaux.

La méthodologie épidémiologique actuelle n'est pas capable d'utiliser ou de synthétiser les données distinctes provenant de petites unités géographiques (villages ou ménages individuels) d'une façon statistiquement acceptable, comme peut le faire le GIS. S'il est mis en œuvre à grande échelle pour promouvoir la planification et la surveillance de la lutte contre les maladies tropicales, le GIS pourrait contribuer à une révision complète de nos connaissances actuelles sur la répartition et la prévalence des maladies tropicales.

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