JUNE 1995

GIS FOR HEALTH *and the* ENVIRONMENT

Proceedings of an International Workshop held in Colombo, Sri Lanka 5 – 10 September 1994

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INTERNATIONAL DEVELOPMENT RESEARCH CENTRE
Ottawa • Cairo • Dakar • Johannesburg • Montevideo
Nairobi • New Delhi • Singapore

Published by the International Development Research Centre
PO Box 8500, Ottawa, ON, Canada K1G 3H9

June 1995

de Savigny, D.
Wijeyaratne, P.
IDRC, Ottawa, ON CA

GIS for health and the environment : proceedings of an international workshop held in Colombo, Sri Lanka, 5–10 September 1994. Ottawa, ON, IDRC, 1995. 184 p. : ill.

/Geographic information systems/, /public health/, /environmental health/, /disease control/, /developing countries/ — /remote sensing/, /spatial analysis/, /disease vectors/, /disease transmission/, /tropical diseases/, /case studies/, /conference reports/, /annotated bibliographies/, references.

UDC: 007:910:614 ISBN: 0-88936-766-3

A microfiche edition is available.

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Monitoring Zoonotic Cutaneous Leishmaniasis with GIS

L. Mbarki[1a], A. Ben Salah[a], S. Chlif[a], M.K. Chahed[d], A. Balma[a], N. Chemam[b], A. Garraoui[c], and R. Ben-Ismail[a]

Introduction

Zoonotic cutaneous leishmaniasis (ZCL), caused by *Leishmania major*, poses an important public health problem in Tunisia, with more than 50,000 human cases being recorded since the beginning of 1983 (Ben-Ammar et al. 1984; Ben-Ismail and Ben-Rachid 1989; Ben-Ismail et al. 1987). The disease is transmitted by a vector of the species *Phlebotomus papatasi*; the reservoir hosts are rodents, namely *Psammomys obesus*, *Meriones shawi* and *M. Libycus* (Ben-Ismail et al. 1987). The geographical distribution of ZCL foci and the propagation of the epidemic in Tunisia were closely conditioned by environmental and ecological factors, including the presence of certain biotopes favourable for rodent hosts, and the development of water resources (dam, wells) and agricultural projects which contributed to an increase in vector population densities (Ben-Ammar et al. 1984; Ben-Ismail and Ben Rachid 1989).

Environmental epidemiology, defined as the study of the spatial or spatio-temporal distribution of disease in relation to possible environmental factors, constitutes an important tool for better understanding the dynamics of parasitic infections and the development of suitable control and prevention strategies (Diggle 1993). GIS is a valuable tool of environmental epidemiology, but has not been extensively used globally in the study of disease distribution and dynamics, although epidemiological data clearly have spatial components. Perhaps the earliest and most celebrated example is John Snow's detection of the Broad Street water-pump as the source of the 1840s cholera outbreak in London. He demonstrated that the association between cholera deaths and contaminated water supplies showed a striking geographical distribution (Diggle 1993; Henk et al. 1991).

[1a]Laboratoire d'Epidemiologie et d'Ecologie Parasitaire, Institut Pasteur, Tunis Belvedere, Tunisia.

[b]Department GIS, Institut Regional des Sciences de l'Information et de Telecommunications (IRSIT), Tunis, Tunisia.

[c]Direction Regionale de La Santé Publique, Sidi-Bouzid, Tunisie.

[d]Direction des Soins de Santé de Base, Ministère de la Santé Publique, Tunis, Tunisie.

In Tunisia, GIS have never been applied to health problems, although there has been geographic recognition of households and manual cartography for improving insecticide coverage within the context of malaria control programs. This approach, although very simple, constituted a valuable tool for the success of malaria control. Unfortunately, this technique was neither improved upon nor replicated for other parasitic diseases such as leishmaniasis and hydatid cystic, or other health hazards heavily influenced by the environment. In fact, this technology could not be sustained manually for two reasons:

- The difficulty of linking multiple and heterogeneous types of data, and
- The overwhelming task of updating dynamic information in the study area.

The advent of computer hardware and software with power and storage capabilities has driven the development of computerized GIS which simultaneously utilize numerous strata of data from a variety of sources. These new technological developments increase the ability of the technology to continuously monitor the pattern of parasitic disease dynamics in Tunisia in both time and space. They also stimulated the introduction of an automated GIS for collecting, storing, retrieving, analyzing, and displaying spatial and nonspatial data regarding parasitic diseases which are highly conditioned by environmental risk factors.

This report presents the preliminary application of an automated GIS for the investigation of the spatio-temporal dynamics of ZCL in relation to potential environmental risk factors, in a pilot focus in Central Tunisia. More precisely, this work aims to:

- Apply the GIS approach in the context of ZCL, to automatically integrate spatial data and attributes related to the disease;
- Display the spatial distribution of cases through time and correlate the occurrence of the disease with environmental risk factors; and
- Refine the calculation of classic epidemetric indices according to the risk level of exposure.

Materials and Methods

The Study Area and Description of Data Collection

The study area covers the "Imadat" (sector) of Felta located in Sidi Bouzid Governorate in Central Tunisia. It is a rural area of 109,850km^2. The primary health care nurse and the sector supervisor carried out a census of the area's total population in 1991, and updated it in 1992 (Ben-Salah et al. unpublished data). Each family in the area was interviewed and their household numbered during door-to-door visits. A pretested questionnaire, used for data collection, contained the following sections:

- Identification of the household:
    - Code of Governorate;
    - Code of Delegation;
    - Code of the "Imadat";
    - Number of the house; and
    - Number of the family
- Description of the dwelling:
    - Type of roof (cement, metal, other);
    - Description of the walls (covered with cement, uncovered);
    - Presence of shelter for animals; and
    - Number of dogs
- Socioeconomic parameters:
    - Profession;
    - Level of parental education;
    - Mode of water supply;
    - Mode of excrement disposal;
    - Availability of electricity and presence of television; and
    - Mode of access to primary health care services
- Family members and other inhabitants:
    - Status in the family: mother, father, son, etc.;
    - Sex;
    - Birth date;
    - School degree; and
    - Occupation
- Information relevant to ZCL:
    - Presence of active lesions or scars;
    - Number of active lesions or scars;
    - sSte of the lesions; and
    - Year and month of the occurrence of ZCL

From 1983 to 1990, the information on ZCL was sought by skin examination performed by local nurses involved in the survey of all individuals in the study area. The face was examined first, then the limbs and the trunk. The diagnosis was in fact very easy, as even the mother or elder relatives could show where the scar was located on the patient. When a typical scar was found, the patient or his/her parents or relatives (if a child) indicated the date of lesion occurrence. Since 1991, information regarding active scars has been collected prospectively through a surveillance system.

Collection of Spatially Referenced Data

Aerial photographs at a scale of 1:20,000 obtained from the Tunisian Office de la Topographie et de la Cartographie have been used by the surveyors during the door-to-door visits. These photographs show the precise location of the dwellings, with a number identifying each house fixed in front. A map (1:20,000 scale) of the entire study area was drawn by a specialist map agency using the aerial photographs.

The constitution of a spatially referenced database was performed using a personal computer to introduce two types of information. Non-locational or descriptive data refer to the features or attributes (variables in the survey form describing individuals, animals or habitats).

Locational or spatial data consist of lines (segments), such as the limits of the area, roads, and so on, points (nodes) corresponding to the dwellings, and areas (polygons) colonized by rodents. Spatial data were digitized into independent coverages of the three types using a format A0 digitizer (Summergraphics) in the GIS department of the Institut Regional des Sciences de l'Information et de Télécommunications (IRSIT, Tunis).

The epidemiological geographic information system (EPI–GIS) was realized using the GIS software package ARC/INFO 3.4D Plus (ESRI, Redlands). Thematic maps were printed using a format A0 plotter and an inkjet colour printer.

The absence of an interface for linking the descriptive database management software (ORACLE PC version) to the GIS software (ARC INFO) required the conversion of the ORACLE data tables into a DBF format compatible with INFO, the database manager of ARC/INFO. Thus, it was possible to join the DBF descriptive data tables to the features attribute tables (AAT: arc attribute table; PAT: point/polygon attribute table) using the command JOIN.

The Epi–GIS conceived and developed by the laboratory of Ecology and Epidemiology of Parasitic Diseases (LEEP) team, permitted the mapping of spatial distribution of ZCL over 10 years and to relate this distribution to the potential vegetation cover, particularly to the presence of chenopods. The command INTERSECT was used to overlay biotope coverages with the dwellings.

Buffers around a focal point believed to be the source of the epidemic were generated with the command BUFFER. This focal point corresponds to a cemetery where *P. obesus* colonies were confirmed in 1983 by field observations (Ben-Ismail et al. unpublished data). Distances between this focal point and dwellings with cases were calculated using the command NEAR.

Data Analysis

The mean force of infection (FOI) for the entire period studied, defined as the number of acts of transmission for one individual occurring within a finite period of time (Lysenko and Beljaev 1987), was calculated for the whole foci using the following formula: $Q(x)= e^{-x}$, where: *Q(x)* is the age-specific proportion of susceptibles (free of scars in the context of ZCL), *x* being the group of age. The analysis involved only the under 10 year-old children in order to control possible age-dependence of the FOI.

The assessment of the FOI for each epidemiologic year was performed from the incidence among susceptibles L, using the following formula: $L(x) = 1-e^{-x}$ (Lysenko and Beljaev 1987), where *x* is the epidemiologic year.

Overlay and intersection operations between different kinds of biotopes (I: presence of chenopods, II: presence of jujubier, III: presence of other plants) and clusters of dwellings located inside these biotopes were performed for the estimation of biotope-wise.

Results

A total of 4,269 individuals belonging to 740 families were interviewed through door-to-door visits. The families lived in 562 dwellings which were numbered during the visits. Since the beginning of the epidemic, 1,081 individuals (22.44%) showed evidence of infection based on the presence of typical scars.

The distribution of the incidence of the infection shows two epidemic peaks in 1985 and 1987. The resulting graph shows neither the pattern of the spatial distribution of ZCL, nor its relation to possible environmental factors.

The distribution of the proportion of susceptibles *Q(x)* over the age groups (0–10 years) revealed a trend for decay. Assuming a constant exponential decay over the age groups (Henk et al. 1991), and using the log likelihood method, *Q(x)* was used to estimate the mean FOI for the whole period of time.

It was found to be 0.017 per year, showing that the focus is hypoendemic for ZCL according to the Lysenko and Beljaev classification (1987).

Using the annual information, the number of immunes (new cases and previous cases), and the number of susceptibles, *L(x)* was estimated and the FOI was directly derived for the corresponding epidemiological year.

Table 1 shows the evolution of the force of infection through time, and the different parameters derived from the database for its estimation. These results show that the FOI, far from being stable over time, follow the same trend as the incidence of infection with two peaks in 1985 and 1987.

Table 1. Evolution of the Force of Infection Through Time and the Parameters Used for Its Estimation.

Year	Susceptibles	ZCL Cases	Incidence L	Force of infection λ
1983	3334	15	0.004	0.005
1984	3444	64	0.018	0.019
1985	3489	392	1.112	0.119*
1986	3258	53	0.099	0.016
1987	3351	332	0.099	0.104*
1988	3142	69	0.021	0.022
1989	3183	73	0.022	0.023
1990	3215	21	0.006	0.007
1991	3315	37	0.011	0.011
1992	3486	24	0.006	0.007

*Values of λ corresponding to epidemic peaks in 1985 and 1987.

To visualize the spatial dynamics of the disease, an overlay between the base map of the area and the coverage of the dwellings without cases was achieved (Fig. 1a). The different biotopes encountered in the study area are displayed in Fig. 1b.

Figure 2a,b,c,d, presents maps displaying the spatial distribution of dwellings with ZCL cases, for the years 1983, 1985, 1987, and 1992, respectively. The location of the first cases which occurred in 1983 (Fig. 2a), allowed the identification of the initial starting point of the epidemic in a cemetery that had been highly colonized by the *Psammomys obesus*, the main reservoir of the parasite.

The capabilities of the EPI–GIS were applied to select clusters of dwellings according to the kind of biotope where they were located. This procedure permitted the comparison of the FOI in different biotopes during the epidemic years of 1985 and 1987 (Table 2). The results showed a large heterogeneity of the force of infection in the different selected biotopes, ranging from 0.23 in the biotope of chenopods to 0.01 in other biotopes in 1985, and confirmed that the distribution of ZCL is very sensitive to environmental factors.

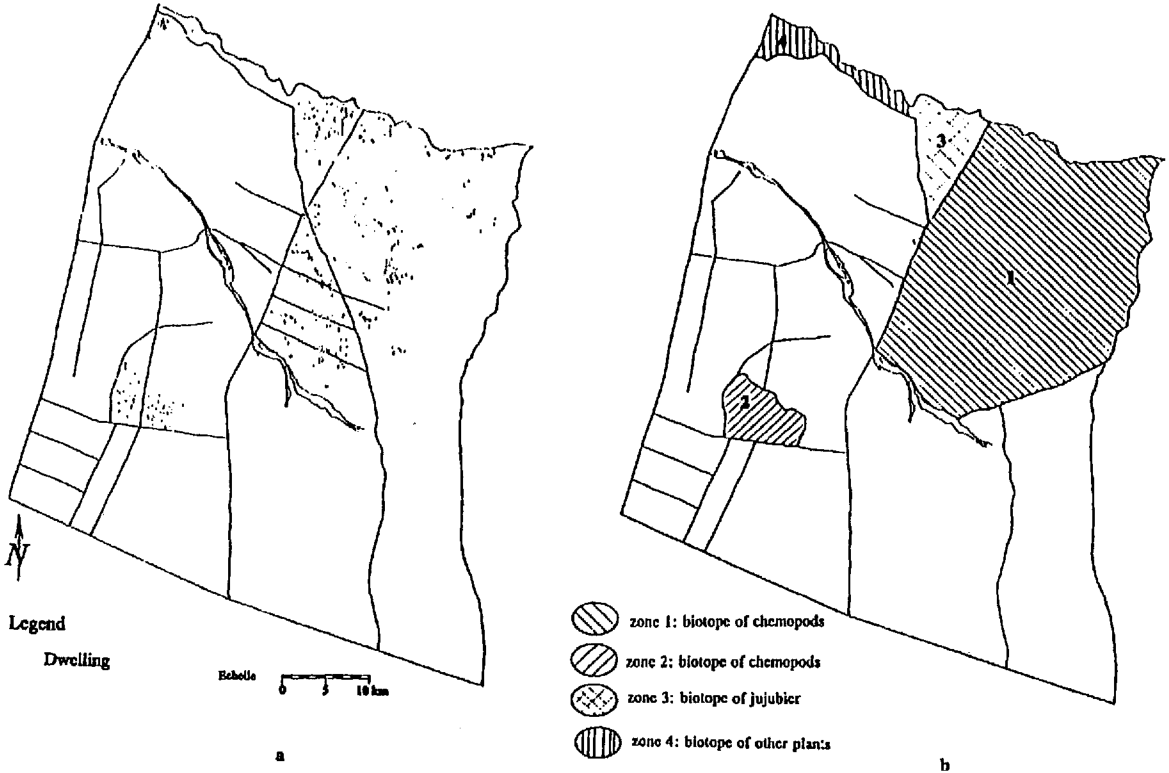

Fig. 1 a. A map displaying the distribution of the dwellings in the study area of felta.
b. A map showing the coverage of vegetation encountered in felta.

Fig. 2a,b,c,d. Distribution of maximum, minimum, and mean distances between the cemetery constituting the starting point of the epidemic and the dwellings with ZCL cases through time.

a. **Location of the dwellings with the first cases of ZCL epidemic in 1983 near an area highly colonized by *Psammomys obesus* the main reser voir of the infection.**
b. **Spread of ZCL to the surrounding dwellings during the epidemic year of 1985.**
c. **Extension of the epidemic to the dwellings located in the north-east of the area during the epidemic year of 1987.**
d. **Distribution of dwellings with sporadic cases in 1992.**

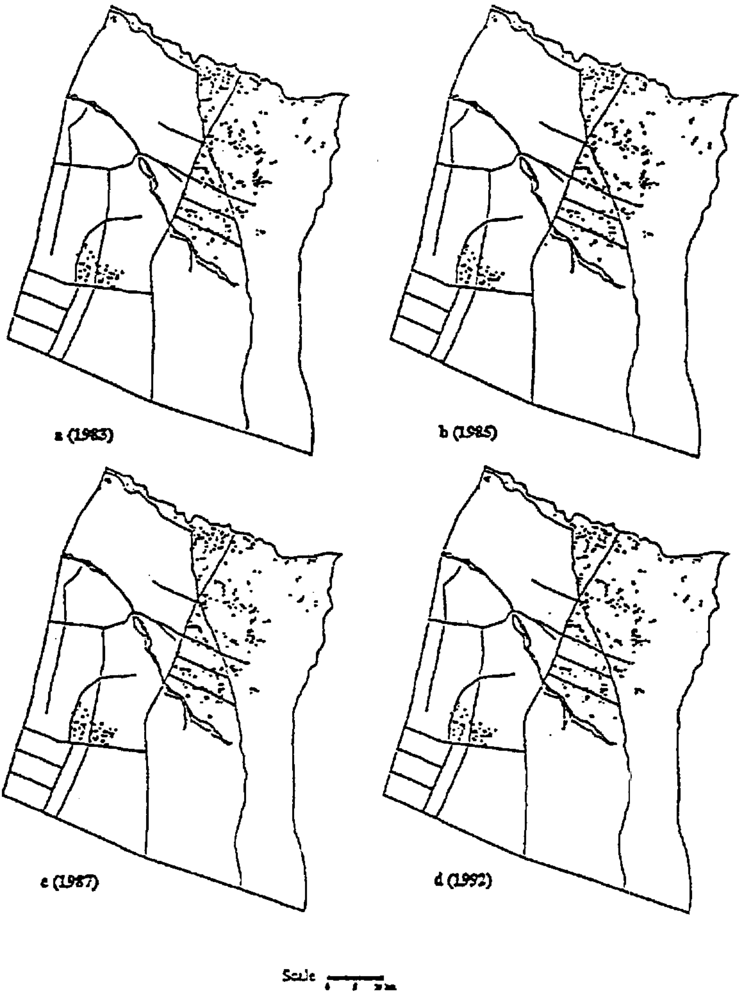

Table 2. Estimation of the Force of Infection λ in Different Biotopes during the Epidemic Years (1985, 1987).

Type of Biotope	Population Size	Susceptibles	ZCL cases	Incidence	Force of infection λ	Level of endemicity *
1985						
1	2578	2126	239	0.112	0.119	méso
2	373	340	71	0.209	0.234	méso
3	656	635	23	0.036	0.037	hypo
4	201	189	3	0.016	0.016	hypo
1987						
1	2373	2309	354	0.153	0.166	méso
2	346	346	28	0.081	0.084	méso
3	606	597	1	0.002	0.002	hypo
4	185	185	9	0.049	0.05	hypo

1 and 2: biotope of chenopods with borrows of the rodent *Psammomys Obesus* the main reservoir of ZCL.

3: biotope of jujubier with borrows of the rodent Meriones shawi secondary reservoir of ZCL.

4: other kinds of plantation having no relation with the reservoir of ZCL.

*: the level of endemicity is rated according to Lysenko and Beljaev classification.

Indeed, in the biotopes 1 and 2 of chenopods the population of rodents is very dense, and individuals are exposed to a high risk of transmission. In these biotopes, the infection is mesoendemic, while it is hypoendemic in biotope 3, where the transmission is expected to be lower due to the absence of the infection reservoir. This analysis confirmed the heterogeneity of the transmission within the same small focus.

Buffers were generated every 200m around the cemetery at the beginning of the epidemic in 1983, to estimate the evolution of the FOI around this starting point.

The distances between the starting point of the epidemic and the dwellings with cases ranged between 251m and 1,102m in 1983. The maximum distance increased very quickly in 1984 to reach 2951m, and remained almost unchanged over the following years.

Discussion

A retrospective survey undertaken in the endemic sector of felta permitted the estimation of the crude prevalence of ZCL and the distribution of incidence through time. It clearly demonstrated the importance of ZCL as a public health problem in the study area and the need for control measures.

The calculation of such classical epidemiological indicators usually includes the whole population surrounded by administrative boundaries of the district for deriving the indicator denominator (incidence, prevalence), assuming that all individuals are under an equal risk of infection. This assumption, although plausible for many health problems, is clearly misleading for vector-born zoonosis where the abundance of both the vector and the reservoir is highly dependant upon the type of biotope where people are living. Within the context of ZCL, the EPI-GIS combined demographic, medical, and geographic data, and allowed the estimation of FOI through time and space. It also facilitated the study of relationships between the distribution and diffusion of the disease, and environmental risk factors. It offered the opportunity to test the plausibility of the basic assumptions of Lysenko and Beljaev's model (the homogeneity of the transmission through time and space) (1987). It was clearly demonstrated that these assumptions are unrealistic in the Tunisian context, raising the need for considering spatial heterogeneities and instability through time in the estimation of the force of infection.

GIS clearly confirmed the role of chenopods as determinants of transmission, and permitted the display of precise spatial distribution of infection. This result corroborates previous findings based on different epidemiological approaches (Ben-Salah et al. 1994). GIS allowed the refinement of epidemiological parameters and the stratification of the studied area to different levels of risks for the transmission, which has very important implications in terms of understanding the determinants of the infection, its dynamics, and the allocation of resources for control.

By evaluating the distances between the source of the epidemic and the dwellings with cases, the reach of an epidemic of ZCL is estimated as approximately one kilometre. Such information is extremely important for designing control measures based on environmental changes, such as plowing the zones of chenopods. It informs precisely on the minimum area necessary to be ploughed to interrupt the transmission of the infection to people.

This approach appears to be more realistic than one based on the measurement of sandfly vector dispersal (maximum flight distance) (Killick–Kendrix et al. 1984). This research stimulated the collection of other environmental factors such as soil type, climatological parameters, waterways, and proximity to parasite sources to establish the relationships between these parameters and the spatial patterns of the disease.

In the context of ZCL, EPI–GIS provides a excellent framework within which the overlaying of a large number of geographical factors (coverages) and the association of them with the disease, the vector, and the reservoir can be undertaken. The GIS approach will become more important if the present research is extended to a larger geographical region. As more data on the trophic preferences and dynamic of the reservoir population become available, the EPI–GIS can assist epidemiologists to predict the spread and establishment of the disease in new locations which constitute a valuable tool for resource allocation and the implementation of preventive measures.

Acknowledgments

This investigation received financial support from the UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases (TDR/RSG, Grant: ID: 890266), from the "Secrétariat d'Etat à la Recherche Scientifique et à la Technologie de la Tunisie" (Projet DRDT RF 2170), and from IDRC, Canada (Project Ref. 92–0233).

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