The Use of GIS To Identify Environmental Factors Associated With Cutaneous Leishmaniasis Transmission Risk In Northeast Sinai, Egypt.

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ABSTRACT In recent years, the number and areas of remote sensing and geographic information systems applications have been increasing. One of the main new areas of application is environmental health. In Egypt, zoonotic cutaneous leishmaniasis (ZCL) is endemic in North Sinai governorate where it is transmitted by the sand fly *Phlebotomus papatasi*. The ecology of ZCL is complex and involves interactions between flies, rodents, parasite, man and the environment. Thus, GIS can provide a suitable framework within which such factors can be integrated, analyzed and modeled. The present work deals with the use of GIS technology to map vector ecological parameters (sand fly composition, abundance and infection rate) and environmental variables (geology, hydrogeology, soil types, etc) in relation to ZCL transmission risk. GIS functions were used to identify environmental indicators of high risk foci as indicated by *P. papatasi* density and natural promastigote infection. Our analysis suggests that ZCL transmission risk is higher at natural habitats characterized by inter-dune clayey sand soils. Identification of the environmental factors associated with the disease will not only allow for mapping its current spatial patterns, but for predicting its distribution under future developmental and/or environmental changes.

KEY WORDS GIS, Landscape Epidemiology, Cutaneous Leishmaniasis, Sand Flies.

1. Introduction

The ecology of cutaneous leishmaniasis (CL) is complex and involves interaction among vectors, reservoirs, hosts, and the environment. Entomological studies carried out in Egypt proved that *Phlebotomus papatasi* is the vector of zoonotic cutaneous leishmaniasis (ZCL) in Sinai (Fryauff et al., 1993). Highest densities of *P. papatasi* occurred during the period May-September (Merdan et al., 1992; Fryauff et al., 1993; Hassan et. al., 1999). The distribution and abundance of sand flies in Sinai are heterogeneous (Merdan et al., 1992; Fryauff et al., 1993). Such heterogeneity appears to be influenced by particular habitats and/or landscape conditions/features (Fryauff et al., 1993; Hassan et al., 1999).

On the other hand, distribution of ZCL in Sinai is focal and disease prevalence varied within small patial scales (< 6km) (Faris et al., 1988; Fryauff et al., 1993). Geographic proximity to sand fly habitats usually determines levels of exposure and risk to CL infections is mostly higher at the peripheries of villages or at uninhabited areas (Faris et al., 1988; Kamhawi et al., 1988).

Variation in the spatial disease patterns is usually influenced by environmental and landscape factors, which often determine the distribution and abundance of vectors and reservoirs. Disease occurrences were reported to be geographically associated with particular vegetation (Mbarki et al., 1994), or soil types (Schlein et al., 1982). Land use and modification of natural habitats are additional factors contributing to alteration in vector and reservoir population densities and disease risk (Yuval, 1991; Fryauff et al., 1993; Mbarki et al., 1994; Hassan et al., 1999). Moreover, our recent studies have indicated that sand fly distribution in central and southern Sinai is modeled by soil types and underlying geology (Kassem et al., 1999).

Despite the apparent geographic heterogeneity in ZCL prevalence and in the distribution and abundance of both vectors and reservoirs in northern Sinai, no studies have been designed to identify factors that underlie such variation and

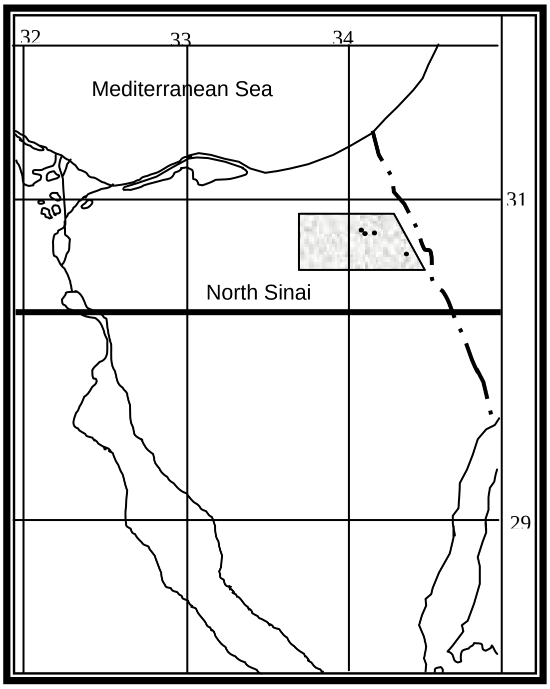


Figure 1: Map of Sinai showing study area (shaded polygon) and study sites (black dots)

influence disease risk. The use of an environmental epidemiological approach, defined as the study of the spatial or spatio-temporal distribution of disease in relation to possible environmental factors (Diggle, 1993), constitutes an important tool for better understanding the dynamics of vector-borne infections and the development of suitable control strategies. Geographic information systems (GIS) are valuable tools of environmental/landscape epidemiology due to its power in integrating, analyzing and modeling several sets of data within a spatial context. In the last decade, GIS technologies have been used to characterize the landscape epidemiology of several human diseases. The diseases, their vectors, and the environments studied varied considerably suggesting the possibility of widespread application of these technologies.

The purpose of the present investigation is to use GIS to identify environmental factors associated with ZCL transmission risk, as defined by *P. papatasi* abundance and natural promastigote infection. The identified factors are then used, in the GIS environment, to generate a preliminary disease risk map for the study area.

2. Material and Methods

2.1. Study area and sites

This study was undertaken at a representative polygon of North –East Sinai (Fig. 1). Preliminary surveys were carried out at eight sites along a 200 km stretch south of El Arish city. The surveys indicated that there are three main habitats/environments in that area, namely natural, agricultural and urban. Therefore, out of the eight surveyed sites four were selected for the present study that represented the main habitats of the area. The study sites are: Sad El Rawafaa (N30^{o} 49$^{/}$ E34 ^{o} 08$^{/}$, site 1), Abu Aujila (N30^{o} 50$^{/}$ E34^{o} 07$^{/}$, site 2), Aum Shihan (N30^{o} 49$^{/}$ E34^{o} 10$^{/}$, site 3) and El Qosayema (N30 ^{o} 40$^{/}$ E34 ^{o} 22$^{/}$, site 4). Sites 1 and 2 are natural habitats with least disturbance, while site 3 is agricultural and site 3 urban. Geographic locations of study sites were determined using a GPS equipment (GPS 12xl Personal Navigator, Garmin, Europe LTD).

2.2. Sand flies

Sampling for sand flies was carried out during the peak activity period extending between May and October (Merdan et al., 1992; Frayauff et al., 1993) of 1996 and 1997. Sand flies were routinely collected for 3-4 nights each month. They were randomly trapped using oiled paper sticky traps, and selectively captured by Centers for Disease Control (CDC) traps operated in flies-human contact points. Fifty paper traps and 4-6 CDC traps were placed in fixed locations at each site to provide measures of species composition abundance (density), sex ratio and natural promastigote infection rate. Flies obtained in paper traps were processed as described by Kassem et al. (1999). Those captured in CDC traps were held inpaper cups provided with water-soaked cotton pads as a source of moisture. In the laboratory, they were cold anesthetized, sorted by sex, and females were identified and 10% of those were dissected under sterile conditions to determine natural promastigote infection rate

2.3. ZCL risk criteria

ZCL transmission risk was determined as a combined measure of *P. papatasi* density and natural infection rate (Fryauff et al., 1993). *P. papatasi* densities (based on paper trap data) and natural infection rates obtained for study sites were used as inputs in a hierrarchial cluster analysis test (SPSS, statistical software, Ver. 6) to categorize these sites into high and low risk groups. Using such group assignment and their geographic locations, environmental factors associated with sites of high ZCL risk were identified using GIS.

2.4. GIS data base and analysis

The input environmental variables used in the GIS analysis were selected based on their direct/indirect influence on the ecology ZCL (mainly vectors and reservoirs). These variables are: soil type, geology and hydrogeology. Accordingly, the following thematic data layers were generated in a PC ArcInfo GIS environment:

1. geographic locations of study sites
2. soil map : digitized from a source map (scale 1:500000) produced by The Decision Support Center, Cabinet of Ministers (1997).
3. Geological map: digitized from maps (scale 1:250000) produced by the Egyptian Geological Survey & Mining Authority (1993).
4. Hydrogeological map: digitized from maps (scale 1: 250000) produced by Research Institute for Water Resources (1992), and contained contours of underground water quality that was digitized on a separate layer (line coverage).

Observations made in the field were used to refine and correct information on the geo-physical environment accompanying the used maps (low-resolution maps).All thematic data layers were co-registered and the obtained entomological data were linked to the respective geographic location of study sites as attributes.ZCL risk membership, determined by cluster analysis, was also attached to those sites. To identify the environmental factors associated with high- risk foci, geographic locations of study sites, labeled high/low risk, were overlain on each of the environmental thematic layers. Thus, the feature class of each theme associated with high risk foci is determined.GIS was then used to select and map all polygons belonging to the identified feature in each theme. The output is four new layers each depicting the distribution of the corresponding factor associated with high risk foci over the whole study area. As high ZCL transmission risk is associated with a combination of environmental factors, and since the spatial patterns of these factors are heterogenous, GIS spatial operations were used to identify areas where all these factors coexist. spatial operations were used to identify areas where all these factors coexist.

3. Results

Sand flies were captured at sites 1,2 and 3, but spite extensive collections at site 4, only one *P. papatasi* was caught during the study period. Density of highest only at site 1. In general, highest sand fly was caught during the study period. Density of sand flies in paper traps, however, was consistently highest only at site 1. In general, highest sand fly densities were recorded during July – September. Overall, 3 sand fly species were caught during this study, two *Phlebotomus* and one *Sergentomiya* species. *P. papatasi* was the most prevalent sand fly species at sites 1,2 and 3. It made up between 87% and 100% of all collections taken at sites 1 and 3. However, it_constituted between 53% and 100% of sand fly collections made at site 2. The sex ratio of captured *P. papatasi* was even at site 1, but was male biased (2:1) in both sites 2 and 3. *P. kazeroni* was generally rare and was collected only once from each of sites 1,2 & 3 during July and August. *S. antennata* was most common at site 1 as it was encountered in all collections where it constituted from 0.8 to 13% of total fly collections. At sites 2 & 3, this species was less common where it constituted between 0.0 and 47% at their sites respectively. Densities of *S. antennata* were highest, however, at site 2 especially during August and September.

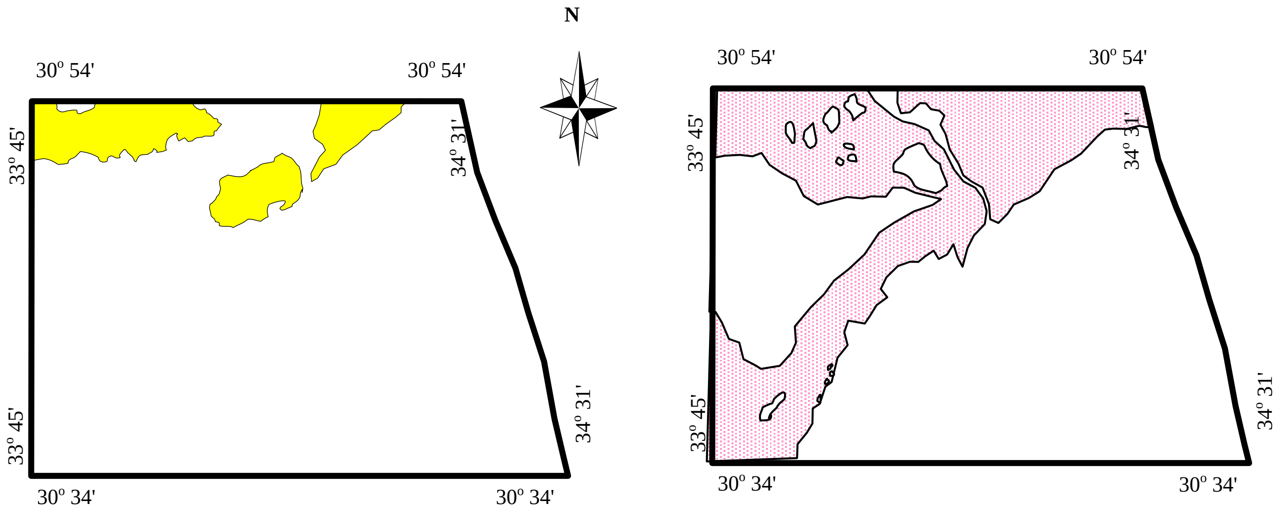
P. papatasi densities based on paper trap collections were variable within and among sampling sites. Densities were consistently higher at site 1 followed by sites 2 and 3 respectively. Fly densities ranged between 0.4 and 6.3 flies/trap with an average of 2.6 ± 1.5 (SE) fly/trap for site 1. Average fly density for site 2 was 0.3 ± 0.1 and for site 3 was 0.08 ± 0.03 fly/trap. Highest *P. papatasi* densities were recorded during July and September for all sites.

Totals of 1681, 1350 and 37 flies were collected at sites 1, 2 and 3, respectively using CDC traps. These collections contained 1314 , 1007 and 22 female *P. papatasi* at the same sites respectively. At site 4, only one male *P. papatasi* was trapped during September 97. Trap indices ranged between 32.8 and 166 with an average of 87.6 for site 1, between 1.8 and 127 with and average of 67 for site 2 and between 1 and 3.4 with an average of 2.2 for site 4. The highest number of female flies were captured during August for sits 1 (830) and 2 (633) and during July for site 3 (17).

Natural promastigote infection among *P. papatasi* was only detected in flies collected at sites 1 and 2. Infection rates for those sites were very high. None of 23 *P. papatasi* females collected at site 3 was infected. At sites 1 and 2 promastigote infections was detected during the months of August and September 1997 with collected at site 3 was infected. At sites 1 and 2 promastigote infections was detected during the months of August and September 1997 with highest rates at September. Natural infection accounted to 8.5% (12/141) and to 6.8% (8/118) for site 1 and 2 respectively.

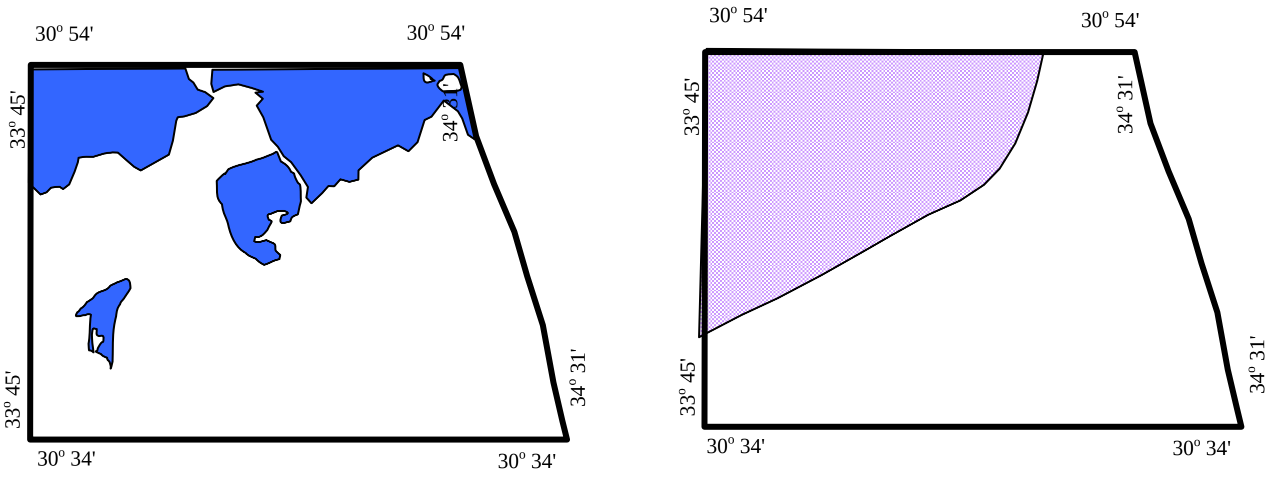
3.1. ZCL risk membership/categorization

Figure 2: Environmental/Landscape Features Spatially Associated with High ZCL Transmission Risk in Northeastern Sinai, Egypt



A. Soil= inter-dune clayey sand

B. Geology= Sand dunes and sheets



C. Hydrogeology= Sand dune deposits occurring over locally productive aquifers

D. TDS= 3000 ppm

Using data on *P. papatasi* density and natural *foci* promastigote infection rate as inputs to hierrarchial cluster analysis, squared euclidean dissimilarity coefficients were calculated and the cluster membership of the four sites was determined (single-linkage dendrogram). The results of this analysis assigned sites 1 and 2 to the high-risk category and sites 3 and 4 to the low risk category.

3.2. Environmental factors associated with high-risk

Based on the results of cluster analysis, high–risk foci appeared to occur within natural habitats while low-risk ones occur within modified environments. Overlay of geographic locations of study sites, labeled with risk category, onto each of the environmental thematic layers allowed the identification of feature classes associated with high-risk foci. High-risk foci (sites 1 & 2) were characterized by inter-dune clayey sand soil occurring over locally productive aquifers. The main geological formation is sand dunes and sheets. At these foci underground water level is 50m and water salinity is 3000 ppm.

Site 3 shared some environmental factors with high-risk foci probably due its proximity, however it was found to occur on a different soil type (active sand dunes). Meanwhile, site 4 was characterized by a landscape totally different from that of high-risk foci (greyish white, highly disturbed limestone occurring on strata with essentially no groundwater).

GIS was used to map the distribution of environmental factors identified to be spatially correlated to high- risk foci over the whole study area producing a new composite output map. This map delineates the boundaries of soil, geological, hydrogeological and underground water conditions favoring high ZCL transmission risk in the study area (Fig. 3).

4. Discussion

The present study aimed at identifying environmental factors associated with high ZCL transmission risk, as indicated by sand fly abundance and promastigote infection rate, in north Sinai. Entomological observations made during the present study point out to a changing epidemiological picture of ZCL in this area. CDC trap indices and promastigote infection rates were found to be extremely higher than those reported earlier by Merdan et al. (1992) for the same area. In fact, promastigote natural infection among *P. papatasi* was also 6-8 folds higher than rates reported by Fryauff et al.(1993). Moreover, high promastigote infection was detected at site 2 which had no infected flies a few years earlier (Merdan et al., 1992). The ecological alteration of the original landscape of this area due to development activities may be responsible for such an ascending trend. This situation must be carefully monitored by health authorities to safeguard human health and to mitigate negative impacts.

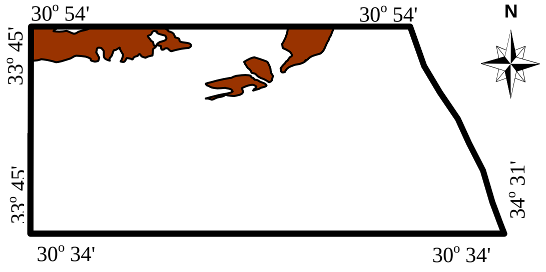
GIS analysis of the relationship between landsca-pe/environmental parameters and ZCL transmis-sion risk indicated that high- risk foci are associated with natural habitats and characterized by inter-dune clayey sand soils occurring over locally productive aquifers. The main geological formation is sand dunes and sheets. In fact, ground observation was of utmost importance in refining the description of environmental factors that were described at a coarser spatial resolution (1:250,000 -1:500000 scale maps). Therefore, observations made in the field were used to re-label the input data.

Of the identified environmental factors, soil type appeared to be the most important. Site 3 (low risk) shared similar geological and hydrogeological conditions with high-risk foci, however both site 3 and 4 occurred at different soil types. Soil type and conditions (texture and humidity) are critical elements of the ecology of sand flies as they constitute breeding and daytime resting sites for flies, as well as habitats for reservoir animals (Saf' yanova, 1979; Artemiev, 1983).

The association of high-risk foci with inter-dune clayey sand soils have ecological grounds. This soil type is characterized by relatively high moisture and organic matter contents, which are necessary ecological requirements of sand fly breeding and survival. These conditions are also conductive of rodents breeding that serve as disease reservoirs. In fact soil type and surface coverage were reported to be the most important landscape variables affecting the ecology of *P. papatasi* and *P. bergeroti* in central and southern Sinai (Kassem et. el., 1999). Although these variables did not limit the distribution of *P. papatasi*, they appeared to model its abundance. Lower numbers of *P. papatasi* were encountered in sand dunes and stony soils. This observation was further corroborated by our findings of the present study, as low *P. papatasi* densities were encountered in site 3 (sand dune soil) while almost no flies were caught at site 4 (chalky limestone). Soil type was also among the most important ecological determinants of the distribution of *P. orientalis*, the vector of kala azar in Sudan (Thomson et al., 1999).

Association of high-risk foci with natural habitats is also consistent with previous reports which indicated that leishmaniasis is dominant in such un-altered environments and along the peripheries of villages (Faris et al., 1988; Kamhawi et al., 1988). Meanwhile, the low sand fly abundance, and consequently lower disease risk, encountered at sites 3 and 4 were associated with altered habitats: agricultural (site 3) and urban (site 4). Hassan et al.(1999) reported that agricultural development in

Figure 3: Map Delineating Areas at High Risk of Zoonotic Cutaneous Leishmaniasis Transmission in Northeastern Sinai, Egypt.



Sinai resulted in decreased sand fly abundance. Kamhawi et al.(1988) also indicated that sand flies were extremely rare in domestic/residential areas (e.g. urban). Disturbance of the natural environment induce destruction of sand fly and rodent breeding habitats, probably reducing their numbers (Hassan et al., 1999).

Based on the identification of environmental factors associated with leishmaniasis transmission, an initial risk map was created in a vector-based GIS which delineates the overall area where ZCL transmission risk may be high. Although it is not to be considered a definitive product, it provides useful information on the spatial boundaries of the risk of contracting CL. It also demonstrated the functionality and power of GIS in studies of landscape epidemiology. In fact this map should be used as a basis for more detailed studies covering a wider area and focusing on the environmental factors identified in the present study.

The produced map could also be further refined using a mask layer indicating natural landscapes which are associated with high transmission risk and vector densities (Faris et. al., 1998; Hassan et.al., 1999). When mask layers of future develop-ments are used, areas at high ZCL transmission risk would be identified and proper mitigation, moni-toring and control measures could be formulated and spatially optimized to save money, effort and time and fulfil planning requirements.

Assessing the relationship between environmen-tal parameters and disease in a quantitative manner is fraught with difficulties since the prevalence of a disease may vary within a small area and the data collected at a limited number of points are not necessarily applicable to a broader region. There are also important logistical and financial constraints to the organization of widespread and repeated surveys. Consequently, the assessment of risk in an area must be extrapolated from a limited number of surveys that are spatially and temporally limited (Thomson et al1999). Therefore, the results of the present investigation were not stratified over a large area in order not to compromise accuracy or overestimate prediction.

Our analysis suggests that ZCL transmission risk is higher at natural habitats characterized by inter-dune clayey sand soils. Identification of the envi-ronmental factors associated with the disease will not only allow for mapping its current spatial pat-terns, but for predicting its distribution under future developmental and/or environmental changes.

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