NASA-CR-204528

FINAL

NCC 2-860
MAY 1 4 1997

Use of remote sensing surveillance to monitor environmental parameters associated with mosquito abundance and vector-borne diseases

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Introduction

Lymphatic filariasis persists as a major cause of clinical morbidity and a significant impediment to socioeconomic development in various parts of the world including Egypt. In Egypt, filariasis has been endemic since time immemorial (Baz, 1946). Early epidemiologic studies identified *Culex pipiens* L. as the main vector of the disease and also showed that the geographic distribution of the disease is highly focal and concentrated in lower Egypt (Khalil, 1935?; 1936; 1939). Between 1950 and 1965, a large scale filariasis control program was carried out by the Egyptian Ministry of Health (EMOH) in the endemic areas. Control efforts led to a steady decrease of the disease in areas of the country previously identified as endemic (Mahdi et al., 1968; a & b; Shawarby et al., 1965;1968). However, spot surveys conducted in various parts of the Nile Delta during the 1970's (Southgate, 1978) and 1980's(Fiensod et al., 1987) revealed that the downward trend of the disease had stopped and that the prevalence and intensity of microfilaraemia had increased.

Subsequent studies carried out by the EMOH revealed that the prevalence of lymphatic filariasis had increased from <1% in 1965 to >20% in 1991 and that the distribution of the disease is focal (Harb et al., 1993). The study also pointed out that high prevalence and negative villages appeared similar in their environmental, social, and agricultural features. However, no attempts were made to study and map the environmental and/or landscape features associated with such disease pattern. Furthermore, the physical and biological variables that prevent, limit or enhance filariasis transmission remain poorly understood.

It has long been recognized that the geographical and temporal distribution of many vector-borne diseases are regulated by climate, landscape, and human activities. The relationship among these factors were formalized in Pavlovsky's research and writings in landscape epidemiology (Pavlovsky,1960;1966). The landscape epidemiologic approach to the study of disease is based on the identification of environmental factors that collectively determine the temporal and spatial distribution of vectors and disease (Pavlovsky,1966; Meade et al., 1988). Factors such as temperature, rainfall, and humidity influence the ecology of vectors (Rajagopalan et al., 1977, Wijers, 1977; Strickman et al., 1995) as well as the development of parasites within vectors (Omori,1958; Brunhes,1969). Vegetation type and distribution are also determined by these variables and influence vector population dynamics (Jachowski, 1954; Ramalingam, 1968; Reisen et al., 1995). Conventional methods used to study and monitor such factors usually involve a lot of time, effort, and money, specially over large areas. In fact, a landscape-based

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approach using remote sensing and geographic information system (GIS) technologies can offer an objective, innovative, and potentially cost-effctive means to identify and map landscape features associated with disease foci.

In the recent decade satellite-borne sensors integrated with GIS have been used to characterize, on varying scales, the landscape epidemiology of several human diseases. Early studies concentrated primarily on identifying and mapping vector habitats or assessing factors related to the quality of vector habitat (Linthicum et al., 1987; Rogers & Randolph, 1991; Kitron et al., 1991; Pop et al, 1992; Wood et al., 1992). Recent studies have begun to investigate the use of remote sensing and spatial analysis to identify and map landscape elements that collectively define vector and human poulation dynamics related to the risk of disease transmission (Dister et al., 1993; Beck et al., 1994; Glass et al., 1995). The diseases, vectors, and the environments studied varied considerably suggesting the possibility of wide-spread application of remote sensing and GIS technologies to improve the understanding of disease processes and control efficiency.

In the present research, we mapped and analyzed the spatial distribution of filariasis (based on microfilarial rates) as it relates to landscape features in the Nile Delta to better understand focality and to determine potential landscape elements that could be used to predict endemicity. This information could be used to predict spatial disease patterns over unsampled areas and, to develop regional maps of transmission risk, thus directing control efforts more effectivley.

Material and Methods

Study area:

After passing Cairo, the Nile takes a north-westerly direction for some 20 km, then divides into two branches: the Rosetta branch (c. 239 km) to the west and the Damietta branch (c. 245 km) to the east, which form the Nile delta. The length of the delta from the south (north of Cairo) to the north (the Mediterranian Sea) is 170 km and from east to west its breadth is 220 km. The area of the delta is about 22 000 km^2 which comprises about 63% of Egypt's fertile land (Zahran & Willis, 1992).

In the Nile delta aridity gradually decreases northwards. At the Delta Barrages (south delta) and Tanta (mid-delta) the annual rainfall is 20.8 mm and 45.5 mm respectively. On the northern part of the delta rainfall increases to c. 102 mm in the east and 200 mm in the west. Winds are generally light but violent dust storms and sand pillars do occur.

The present study involves 11 districts belonging to 5 governorates located in the southern to mid delta region and covering some 9004.5 km^2. This area is mainly rural with various urban and industrial centers connected by a major network of roads. Monthly temperatures (maximum and minimum) and relative humidity appear to vary within 1-3^{o}C and 9-13%, respectively, over the study governorates (Egyptian Metreological Authority, 1994).

Epidemiological data

Microfilaraemia (mf) prevalence data were collected by the EMH teams. From each person a 20 ul finger-prick sample of blood was taken during the peak of periodic microfilaraemia, usually between 22 h00 and 02 h 00. Blood samples were stained with Giemsa and examined qualitatively for *Wuchereria bancrofti* (Cobbald) microfilariae. The population samples usually represented ~10% of the total population residing in each sample community.

The data available for the presenst research were collected between 1986 and 1988. Study districts and number of villages sampled together with demographic data on districts' populations (Egyptian government population census, 1986) are shown in table (1). For statistical analyses, communities were grouped into two discrete categories using partitioned cluster analysis (Sokal and Sneath, 1963), which allows an observation to appear in only one cluster. Those categories are : low prevalence (=<3.6%, n= 157) and high prevalence (=>3.7%, n= 44) (df= 1, 199; F= 522.008; P = 0.0001).

Remotely sensed and GIS data

A major part of the present study was to use remotely sensed data to identify and map the landscape features in the study area. The satellite data used in the present study were acquired by Landsat-5 Thematic Mapper (TM) on July, 1987 (zone 36, path ....?). Each TM picture element (pixel) represents approximately 28.5 x 28.5 m on the ground.

Several spectral indices were produced from satellite data to help interpret and classify landcover around communities. Those indices included a Normalized Difference Vegetation Index (NDVI) (Tucker, 1979) which is related to photosynthetic activity and biomass of vegetation, and moisture index (?). In addition, a tasseled cap transformation was performed on the TM image using the method of Crist et al. (1986). This transformation generated three spectral indices: brightness, greenness, and wetness. Brightness is a measure of total reflectance or soil brightness. Greennes is generally considered to be a measure of the density of green vegetation; wetness represents vegetation and soil moisture (Crisr & Cicone, 1984: Crist et al., 1986), and may be used to differentiate vegetation types (Crist et al., 1986). The study area was visited and the major types and spatial and structural variations in landscape features were identified and located onto the image.

A computer-generated map of landscape features (30 classes) was created using the digital TM data. The algorithm (ERDAS Imagine, V. 8.2,1994), which assigned pixels to categories according to their spectral reflectance, utilized bands 4 (near-infrared; 0.76-0.90 um), 5 (mid-infrared; 1.55-1.75 um), and 7 (mid-infrared;

2.08-2.35), in an unsupervised maximum likelihood classification process. Hard copies of this classification image were used in the field to label major types of landcover.

Four digital thematic data layers in ARC/INFO (geographic information system software, V. 7, ESRI, 1995) were developed: geographic locations of study villages (point coverage), village boundaries (polygon coverage), goverorate boundaries, Nile course, and rainfall contour lines (vector coverages). Village locations were digitized off the TM scene after matching the locations in 1:25,000 political base-maps of the Nile Delta. The boundaries of labelled villages were then digitized from the satellite imagery. Governorate boundaries and rainfall contour lines were digitized from 1:500,000 base paper maps (Egyptian Geological Authority, and Water Research Center, Ministry of Irrigation). All coverages were registered to the universal transverse mercator (UTM) coordinate system.

Field studies

During June 1995, ten communities, representive of different geographic settings and prevalence levels, were visited to investigate the relationships between satellite-derived multispectral data and different features on the ground. Soil moisture was determined in several fields per community and soil samples were collected to determine their types and colors. Interviews with local people were conducted to inquire about temporal patterns of annual croping as well as permanent features since satellite data were aquired on an earlier date.

Larvae of *Cx. pipiens* were collected from 5 test communities and observations were made on major types of larval breeding sites. Larvae were reared in the laboratory and the physiological structure of emerged adults was determined by examining the extent of females ovarian development when 5-7 day-old (Hassan, 1994). All tested samples were found homogenous for anautogeny except that collected from the high prevalence area of Shebin el Kanater district, Qalubiya governorate. In this district, *Cx. pipiens* population was heterogenous with 29% autogenous, 57% anautogenous, and 14% hybrid individuals (n= 50).

Types and frequency of breeding sites varied among the study areas. Cesspits were more frequent in Qalubiya, while in the rest of the areas they were well managed and provided no habitats for mosquito breeding specially in Monoufiya and Gharbiya. Apart from Qalubiya, irrigation/ drainage channels were among the most common breeding habitats for *Cx. pipiens*. Two factors seemed to make them inhabitable by mosquito larvae: dumping of domestic wastes and the presence of huge floating vegetation communities.

During field visits it appeared that in some areas, the same annual crop has been cultivated for over 15 years without rotation due to soil properties. In others particular crop rotation schemes were involved. All agricultural lands including those of permanent crops are flood irrigated. Soils were all moist saturated at 3-10 inches deep, even when they are dry on the upper most layer. All tested soil samples appear to ...(Byron).

In general, fields are very small in size (smaller than the TM pixel size) and crops are in all stages of growth. In Qalubiya, villages are closer to each other and farmlands are relatively of smaller size than in other study areas. In Giza, Monoufiya, Gharbiya, and Dakahliya, villages are separated by long distances and farmlands are fairly large, although fields of a particular crop are still small. Maize seems to be the major annual crop in Qalubiya and large orchards are prevalent specially in the west. In Giza, maize, berseem, and vegetables are the common crops. Maize, cotton, banana and orchards characterize landscapes in Monoufiya. Further north in Gharbiya, large areas are devoted to cotton and rice, with vast lands still being prepared for cultivation. Rice and cotton rather than maize also dominate the landscape in Dakahliya. Again, large areas are still being prepared and rice as well as other crops are in various stages of growth.

Data integration and analyses

Epidemiological data, ancillary thematic data, and remotely sensed data were integrated into the GIS. Microfilaraemia prevalence categories were attached to the point coverage of village geographic locations together with other attributes. These data were used to map and analyze the spatial distribution of filariasis in the study area.

Distances between villages (maximum search distance = 5 km) were calculated using GIS operations to examine spatial clustering of mf prevalence rates. To further study spatial relations, we determined the shortest distance and frequency of mf negative communities occurring next to high prevalence ones within the search distance. To test whether annual precipitation affects filariasis prevalence, GIS was used to overlay rainfall contour lines on village locations coverage, then proximity functions were used to identify villages located at up to 25 km around precipitation lines, to represent communities receiving different amounts of rain. Average mf prevalence in the identified groups were subsequently compared.

For each village, a GIS process known as buffering was used to generate a polygon describing the area within a 1 km distance from a village boundary. The 1 km distance from the village boundary was based on the flight range of *Cx. pipiens* (A. Gad, personal communication). The polygonal buffers were converted to ESRI's raster (GRID) format and merged with the landcover image to calculate the proportion that each landscape element occupied within each village buffer. The same operation was used to determine average brightness, greenness, wetness, NDVI, and moisture index values for study villages. Landscape proportions were subjected to an angular transformation (arcsin P) to normalize the data (Zar, 1984) before statistical analyses.

A discriminant analysis (Afifi and Azen, 1979) was performed using landscape and indicies data to find the combination of variables that best predicts the mf prevalence category to which a community belongs. The combination of predictor variables is called a classification function. This function can then be used to classify new communities whose category membership is unknown (Dixon, 1990). This test was performed using the data sets of Qalubiya and Monoufiya governorates as they contained *ca.* 65% of the study communities, provided a reasonable geographic coverage, and had a more equitable observations between the two mf prevalence levels used during this study.

Reports of the data obtained by GIS operations were exported to "Systat" (statistics software, Systat, Inc., Evanston, Illinois) which was used for all statistical analyses during this study.

RESULTS

Evidence of filaria transmission showed a heterogenous spatial pattern in the Nile Delta (Figure 1). As evidenced by the map, Qalubiya governorate has the highest concentration of the high mf prevalence communities, particularly in Shebin Elkanater district. The map also reflects some spatial characteristics of the disease: that is, high prevalence communities are geographically clustered in Qalubiya, in contrast to other governotaes where there is fewer high prevelence communities which are more dispersed and less clustered. Average mf prevalence decreased from Qalubiya in a south-west, north-west direction where it reached nil in El Santa (Gharbiya governorate) and El Shohada (Monoufiya governorate). Figure 1 also indicates that most high prevalence communities (84%, n = 31) are located on the eastern side of Dammietta branch of the Nile.

Communities with similar mf prevalence rates were aggregated within a 1 km distance. Aggregation then decreases significantly with distance up to 5 km (Pearson correlation coefficient = - 0.98). GIS identified 612 community pairs which were located within a 5 km distance, of those only 1.8% represent cases in which a negative communiyt was found next to a high prevalence one. The shortest distance at which this phenomenon occurred was 1.6 km (one case), however, almost all of these cases was encountered at > 3 km (average distance = 3382.25 m). It should be noted, nevertheless, that in most of these cases the negative villages were closest to other villages, with which they share similar prevalence levels, than to high prevalence ones.

Figure 2 presents the spatial distribution of mf prevalence in the Delta in relation to rainfall. Prevalence rates in communities receiving 25 mm annually (n = 67; mean±SD = 3.9 ± 3.7%) were significantly higher than those receiving 50 mm (n = 134; mean±SD = 1.6 ± 2.1%) (t = 4.07, df = 199, P < 0.0001). In more north-western parts of the study area where rainfall reaches 100-200 mm, no microfilarial individuals were detected.

Incorporating satellite data and groud observations, a 10-class landcover map of the study area was developed. The map shows a large variation in the distribution of landscape elements in the Nile Delta. As can be seen in Figure 3, the composition of landscapes around communities change considerably within a few kilometers.

The results of the discriminant analysis indicated that the most important landscape elements for determining community category were 1) water bodies ($F_{(1,128)} = 5.34$, $P = 0.02$), and 2) marginal vegetation ($F_{(1,128)} = 4.6$, $P = 0.03$). The means for these landscape proportions for the high group were 0.4% water bodies and 3.9% marginal vegetation, whereas the means for the low group were 1.7% and 2.7%, respectively. In addition, the results indicated that wetness ($F(1,128) = 8.3$, $P = 0.005$) and moisture index ($F_{(1,128)} = 6.2$, $P = 0.01$) contribute in the process of discriminating communities. The means of wetness and moisture index for the high group were -10.3 and 17.3 while for the low group they were -7.4 and 17.6, respectively. Overall, the obtained classification functions were able to correctly categorize 79% of the high prevalence communities and 74% of the low, for a total accuracy of 77%.