Geospatial Health 7(2), 2013, pp. 391-398

Socio-environmental variables and transmission risk of lymphatic filariasis in central and northern Mozambique

Isabel Manhenje[1,2], M. Teresa Galán-Puchades[2], Màrius V. Fuentes[2]

[1]*Instituto Nacional de Salud, Ministerio da Saúde, Maputo, Republic of Mozambique;* [2]*Departament de Parasitologia, Facultat de Farmàcia, Universitat de València, Burjassot-València, Spain*

Abstract. Lymphatic filariasis (LF) is endemic in Mozambique, where it is caused by *Wuchereria bancrofti* with *Culex quinquefasciatus* as the main vector. It affects approximately 10% of the population (2 million) with about 16 million at risk. Prevalence rates in 40 out of 65 districts that together comprise the four endemic provinces Niassa, Cabo Delgado, Nampula and Zambezia were analysed with the aim of elucidating the socio-environmental variables influencing the transmission. The levels of prevalence were divided into six ranks and certain climatic, environmental and social factors were considered independent variables. A climadiagram was created and the LF risk and the water budget-based index were calculated for each district. Factors influencing the risk of the overall transmission and that of the provincial levels were established by discriminant analysis. The results show that LF transmission increased with mean maximum temperature and decreased with altitude. The almost constant annual temperature (especially in the tropical area), altitude, general economic conditions and predominant crop production (rice) were found to be responsible for the abundance and presence of the vector. However, despite the presence of the vector in the hinterland, presence and survival of the parasite were not found to be favoured there. The transmission risk was found to be highest in Zambezia, and consequently also the prevalence, while the situation in Niassa was the opposite. The conclusion is that temperature, altitude and the development/poverty index (particularly in the urban areas) have to be considered as transmission risk factors for LF in Mozambique. The extent of rice culturing probably also plays a role with respect to this infection.

Keywords: lymphatic filariasis, socio-environmental variables, transmission risk, Mozambique.

Introduction

Lymphatic filariasis (LF) is a human, parasitic disease caused by *Wuchereria bancrofti* (Cobbold, 1877) Seurat, 1921, in 90% of all cases. The infection is transmitted by various mosquito species of the genera *Aedes*, *Ochlerotatus*, *Mansonia*, *Anopheles* and *Culex*. The World Health Organization (WHO) identifies LF as the second leading cause of long-term disability worldwide (WHO, 1997a). The principal impact of LF in humans is the high degree of disability that leads to reduced mobility and stigma, both of which have inherent repercussions on society and work. The disease is endemic in 83 countries with approximately 66% of those at risk living in Southeast Asia and 33% in Africa, and it has been estimated that about 2% (120 million) of all humans are affected, a third of whom present clinical manifestations, while 1.2 billion people are at risk (WHO, 1997a,b).

In 2000, the Global Alliance, consisting of WHO, the World Bank, United Nations Children's Fund (UNICEF), the Carter Center, the pharmaceutical companies GlaxoSmithKline (GSK), Merck & Co. and various academic institutions and non-governmental organizations (NGOs), launched the Global Programme to Eliminate LF (GPELF) by 2020 (WHO, 1997a). The GPELF strategy is to interrupt transmission of LF by treatment of the entire at-risk population through community-wide mass drug administration (MDA) programmes (Taylor et al., 2010). The drugs are readily available to all countries in need of them thanks to the generous donation of two different drugs: ivermectin by Merck Sharpe and Dohme (a subsidary of Merck and Co.) and albendazole by GSK. The first MDA campaigns were launched in Egypt and Samoa and by 2009, approximately 496 million people at risk in 53 endemic countries had been covered (WHO, 2011). Furthermore, 37 countries are now in the process of completing their fifth MDA and advancing towards the determination to stop MDA and commence post-MDA surveillance (WHO, 2011).

In Mozambique, one of the 39 African countries that are endemic for LF, 16 million people are at risk

Corresponding author:
Màrius V. Fuentes
Departament de Parasitologia
Facultat de Farmàcia, Universitat de València
Avinguda Vicent Andrés Estellés, 46100 Burjassot-València, Spain
Tel. +34 96 354 4298; Fax +34 96 354 4769
E-mail: mario.v.fuentes@uv.es

and 2 million individuals are infected, i.e. about 10% of the total population (MISAU, 2009). Mozambique's northernmost and central provinces are most severely affected, and the mosquito *Culex quinquefascitatus* is considered the most important vector. Studies carried out in the endemic areas have demonstrated the strong influence of the climate (Thompson et al., 1996; Hassan et al., 1998; Lindsay and Thomas, 2000; Sabesan et al., 2006) and also of the socio-environmental conditions (Hunter, 1992; Harb et al., 1993; Sherchand et al., 2003; Erlanger et al., 2005; Bonfim et al., 2011) on the transmission of this human parasitic disease. Moreover, forecast indices based on climate and/or socio-environmental variables have been developed for some endemic areas, such as the LF risk index for the African continent (Lindsay and Thomas, 2000) and the LF transmission risk index for southern India (Sabesan et al., 2006). The aim of this study was to identify which climatic, environmental and social variables influence the transmission of LF most in the endemic area in the northern and central parts of Mozambique.

Material and methods

Study area

The study area comprises the four north-eastern provinces Nampula, Cabo Delgado, Niassa and Zambezia, which form the most fertile part of Mozambique (Fig. 1). The geographical coordinates of selected districts, given in Fig. 2, indicate the approximate situation of the country and study area. The latter can be divided into three climate zones: humid tropical in the North, dry tropical in the South and the tropical high-altitude climate in the mountain areas in the central part. There are two seasons: the dry season ranging from May to September and the wet season lasting from October to April. Two thirds of the population in the study area, approximately 14 million individuals, live in rural areas with an economy mainly based on subsistence farming (IFAD, 2008).

Niassa, the largest (129,056 km^2) and also most mountainous province, is divided into 15 districts. With 1,169,348 inhabitants, it has the lowest popula-

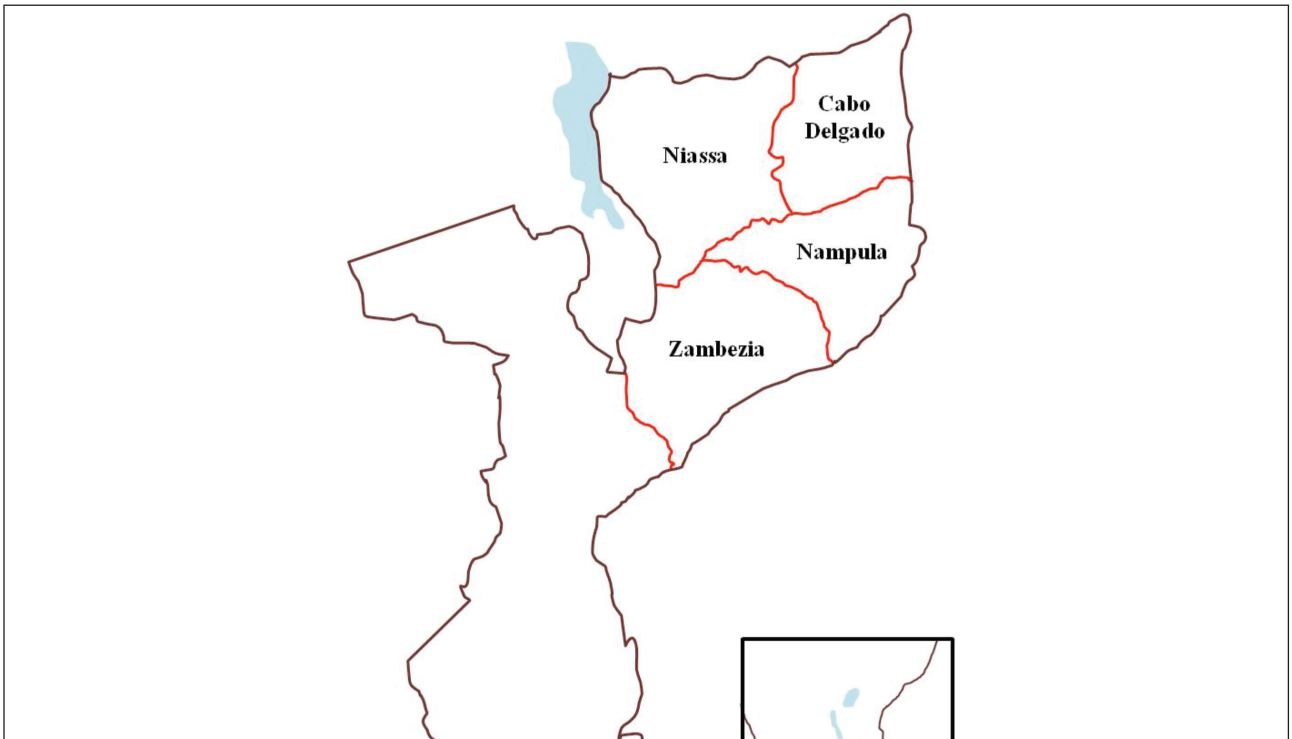

Fig. 1. The location of Mozambique in south-east Africa and the study area comprising the provinces Niassa, Cabo Delgado, Nampula and Zambezia.

tion density in the country (19.0 inhabitants/km^2). Cabo Delgado, covering 82,625 km^2 in the far north-east, is divided into 16 districts and has 1,605,649 inhabitants with a population density of 19.4 inhabitants/km^2. Nampula, situated on the shore of the Mozambique Channel, is the most populous province with 3,985,285 inhabitants translating into a density of 46.2 inhabitants/km^2. It is divided into 18 districts covering 81,600 km^2. Zambezia is divided into 16 districts, covering 103,127 km^2 and has a population of 3,848,276 inhabitants and a density of 37.3 inhabitants/km^2 (INE, 2008).

Of the 65 districts that make up these four provinces, 40 were included in the study (Table 1), taking into account their characteristics and the availability of at least one weather station in each district capable of providing complete sets of climate data.

Prevalence data

LF prevalence data at the district level were obtained from the Ministry of Health in Mozambique, i.e. Ministerio da Saúde de Mozambique (MISAU), which provides information about the most important infectious diseases in its Boletín Epidemiològico (BO), in this case BO 3/2008. The prevalence data for the districts given in Tables 1a and 1b belong to one of the following six ranges:

(i) 0-1% No risk;
(ii) 2-10% Low risk;
(iii) 11-25% Low-medium risk;
(iv) 26-40% Medium risk;
(v) 41-55% Medium-high risk; and
(vi) >55% High risk (Tables 1a,b)

Climate and socio-environmental data

Climatic data, covering 10 to 30 years depending on which climate station provided the data, were collected and used to set up a climate information database containing monthly data on temperature, rainfall and potential evapotranspiration (PET) (Table 1). Data from the 40 climate stations corresponding to each district in the study area were provided by FAOCLIM 2©, the world-wide agroclimatic database (FAO, 2000). Moreover, for each station, a climadiagram was created aiming at the delimitation of the dry and the wet periods. This database was completed with socio-environmental information such as population and surface data as well as information regarding the most important crops produced in the districts, e.g. corn, beans, yucca, peanuts or rice (MAE, 2005).

Forecast indices

Two forecast indices with respect to LF transmission were calculated for each of the 40 study districts, i.e. the LF risk index (LFRI) and the water budget-based index (Wb-bsI). The former index regards the likelihood of LF transmission for the African continent and was proposed by Lindsay and Thomas (2000). This index is a logistic regression used to create a risk map of microfilaremia using a geographical information system (GIS) calculating this risk for a given place according to the formula:

$$\text{LFRI} = l/(1 + e^{-Z})$$

where Z is a factor determined by the following formula:

$$Z = 4.5147 + (0.0114 * R) - (3.1431 * R/PET) - (0.4209 * T_{max}) + (0.3515 * T_{min})$$

where R is the total monthly rainfall, PET the mean monthly potential evapotranspiration and T_{max} and T_{min} the mean maximum and minimum monthly temperatures.

The Wb-bsI is an index based on the monthly rainfall, the monthly PET as well as the T_{max} and T_{min}. This index was originally used for the prediction of fascioliasis transmission in the United States of America (USA) (Malone et al., 1987), in Africa (Malone et al., 1998), in the Andean mountain range (Fuentes, 2006) and in Colombia (Valencia-López et al., 2012). It has also been used for the assessment of malaria transmission in Eritrea (Malone et al., 2003) and to model the ecological niche of hookworm in Brazil (Mudenda et al., 2012). The Wb-bsI was adapted to forecasting LF in Mozambique, through the formula:

$$\text{Wb-bsI} = GDD * R/PET, \text{ if } R/PET > 0.2$$

where GDD is growing degree days (the average annual mean temperature minus the base development temperature) for *W. bancrofti* (Yang et al., 2006).

Discriminant analysis

The attainment of lineal functions of independent variables, named discriminant functions, makes it possible to classify a given place in a subpopulation or established group according to the values of the dependent variable. The LF prevalence ranges were considered the qualitative dependent variable, while the socio-environmental variables were considered as

Table 1a. Population data and physical landscape characteristics by province and district.

	Population (per km^2)	Prevalence (% range)	Altitude (m range)	Mean temp. (ºC)[a]	Rainfall (mm)[a]	PET[b]
Niassa						
Cuamba	30.1	41-55	200-500	24.2	1,009	129
Lago	11.5	0-1	130-1,840	20.4	1,450	130
Lichinga	15.9	0-1	480-1,300	18.3	1,115	116
Marrupa	3.1	2-10	350-1,000	22.1	1,136	123
Maua	6.5	26-40	200-500	24.3	1,170	127
Mecula	0.8	6-40	200-500	24.5	1,419	122
Ngauma	15.4	0-1	200-500	20.6	1,094	116
Cabo Delgado						
Ancuabe	21.9	41-55	200-500	26.0	1,147	123
Macomia	17.6	11-25	500-1,000	25.1	1,198	129
Mecufi	33.5	11-25	200-500	26.9	796	147
Meluco	5.1	26-40	200-500	25.6	1,162	123
Mocimboa	20.5	56-100	≤200	25.3	991	117
Montepuez	10.5	26-40	200-500	24.2	972	127
Mueda	10.8	56-100	200-500	21.9	1,093	113
Namuno	28.9	41-55	200-500	24.7	1,024	124
Palma	14.7	41-55	≤200	26.4	1,139	128
Quissanga	20.4	11-25	≤200	26.2	1,000	145

[a]Annual; [b]Mean annual potential evapotranspiration

Table 1b. Population data and physical landscape characteristics by province and district.

	Population (per km^2)	Prevalence (% range)	Altitude (m range)	Mean temp. (ºC)[a]	Rainfall (mm)[a]	PET[b]
Nampula						
Angoche	82.5	56-100	≤200	25.7	1,074	146
Malema	23.5	26-40	300-1,800	22.0	973	127
Meconta	39.5	56-100	≤200	24.0	933	130
Mecuburi	19.7	26-40	200-500	25.4	1,044	136
Memba	50.3	41-55	≤200	25.9	744	146
Mogovolas	46.0	56-100	200-500	26.1	1,042	134
Mogincual	24.9	56-100	≤200	25.7	1,008	135
Moma	49.8	56-100	≤200	25.9	1,167	135
Mossuril	31.2	11-25	≤200	25.2	1,029	146
Namapa-Erati	53.9	41-55	200-500	24.9	972	136
Nampula	41.5	41-55	200-1,200	23.4	1,038	130
Ribaué	31.4	2-10	200-600	23.7	1,125	119
Zambezia						
Alto-Molocué	36.2	2-10	400-1,000	22.9	1,403	113
Chinde	37.7	56-100	≤200	25.5	1,200	133
Ile	49.5	2-10	200-1,000	23.0	1,615	114
Lugela	21.7	11-25	200-1,000	24.7	1,628	119
Maganja	37.3	11-25	≤200	25.2	1,307	145
Milange	42.5	2-10	200-1,000	22.9	1,735	112
Mocuba	31.8	11-25	100 - 400	24.6	1,175	114
Morrumbala	23.8	26-40	400-2,000	23.5	1,017	129
Namacurra	99.1	11-25	≤200	25.7	1,169	138
Namarroi	38.8	41-55	400-1,000	23.4	1,758	115
Pebane	16.6	2-10	≤200	25.2	1,225	136

[a]Annual; [b]Mean annual potential evapotranspiration

quantitative independent variables. These variables included the annual precipitation, the number of months with rainfall, the PET, the mean annual relative humidity, the mean annual maximum temperature, the mean annual minimum temperature, the mean annual temperature, the mean annual night-time temperature, the mean annual daytime temperature, temperature differences, altitude, population density, and the LFRI and Wb-bsI values. Discriminant analysis was carried out for all climate stations together and separately for each of the climate stations of the provinces studied. Statistical significance was established at P <0.05.

Results

Climate

The climadiagrams, created for each of the climate stations in the 40 districts, show the delimitation between the wet and the dry season. They also allow the evolution of rainfall and temperature along the climatic year in the southern hemisphere to be graphically denoted, here starting in July and ending in June. Representative climadiagrams for each province with regard to climate variables and LF prevalence data are shown in Fig. 2. They demonstrate that the temperatures are stable over the year, generally varying between 20 ºC and 25 ºC, with the exception of districts situated at a higher altitude and in the hinterland, e.g. Lago in Niassa province, where the minimum mean temperature reaches 16 ºC. Between January and March, the rainfall variable peaks, usually above 200 mm. The wet season, by and large, lasts 6-7 months, from November to April/May.

Forecast indices

All LFRI values obtained were very similar, close to 1, which means that the potential transmission of LF is, according to the index, very high in all districts. Among the results obtained for each province (Table 2), the highest value was obtained for the Milange district in Zambezia province, while the lowest value was found in Malema, Nampula province.

The Wb-bsI results are absolute values and do not correspond to potential generations of *W. bancrofti* as the index value necessary to complete its life cycle remains unknown. Among the results obtained for each province (Table 2), the highest value was obtained for the district of Lugela, Zambezia province and the lowest in Lichinga, Niassa province.

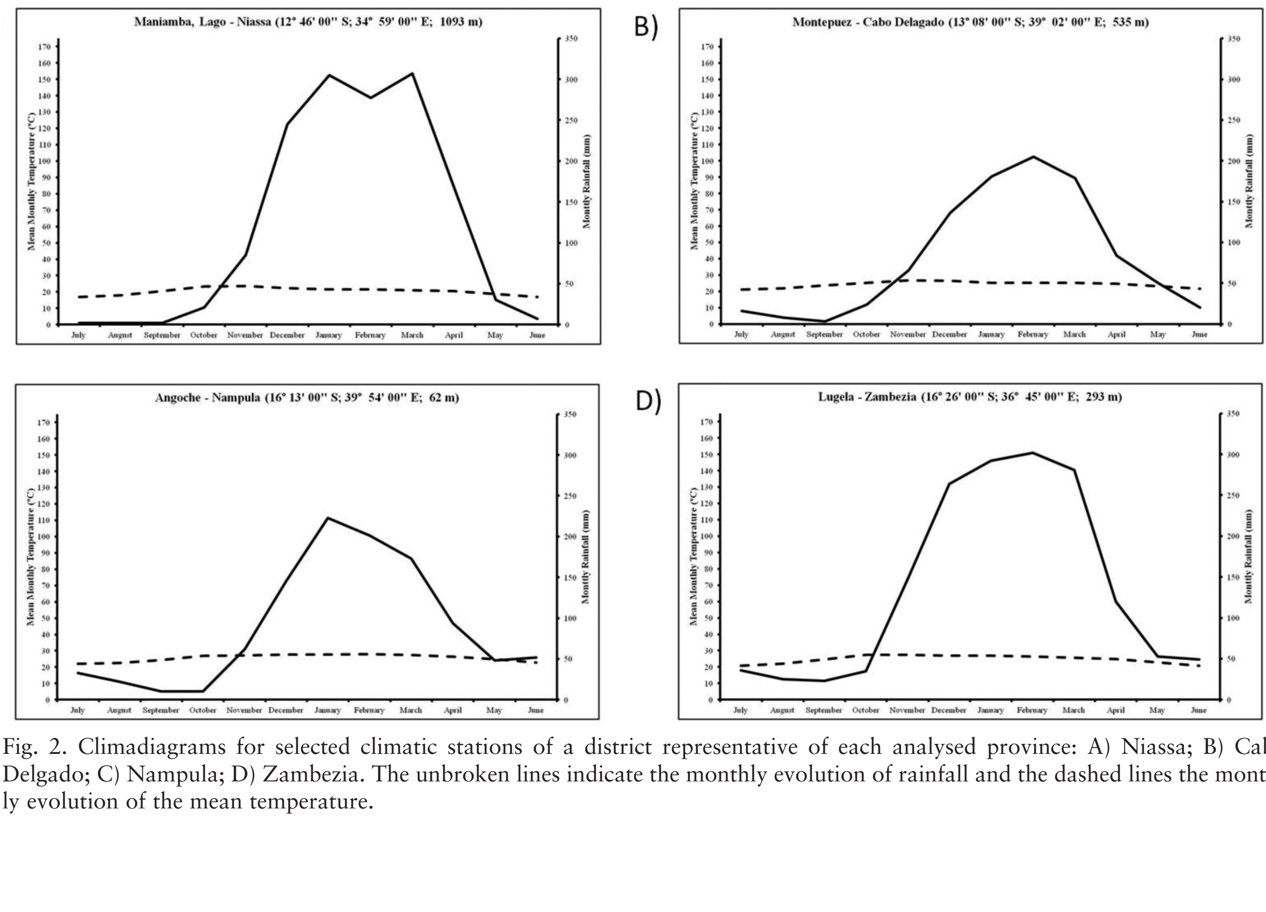

Fig. 2. Climadiagrams for selected climatic stations of a district representative of each analysed province: A) Niassa; B) Cabo Delgado; C) Nampula; D) Zambezia. The unbroken lines indicate the monthly evolution of rainfall and the dashed lines the monthly evolution of the mean temperature.

Table 2. Selected values of LF indices by district and province.

Province	LF risk index (LFRI)				Water budget-based index (Wb-bsI)			
	Maximum		Minimum		Maximum		Minimum	
Niassa	Mecula	0.999994	Cuamba	0.999183	Mecula	3,132	Lichinga	988
Cabo Delgado	Macomia	0.999945	Mecufi	0.998073	Ancuabe	2,910	Mecufi	1,824
Nampula	Moma	0.999964	Malema	0.995263	Moma	2,563	Malema	1,488
Zambezia	Milange	0.999999	Morrumbala	0.999430	Lugela	3,461	Morrumbala	1,560

Discriminant analysis

The global discriminant analysis for selected districts and climate stations, among all independent variables considered, including forecast indices, maximum mean temperature (F = 19.14) and altitude (F = 11.19) are considered the only variables determining LF prevalence in a statistically significant manner (P <0.0001), providing two canonic discriminant functions, capable of explaining 76.5% of the variance of LF prevalence from function D_1 and the remaining 23.5% from function D_2, i.e. 100% of variance (Table 3). Moreover, 60.0% of the districts studied were classified in the same prevalence ranges as those provided by MISAU.

Variables included in the canonic discriminant functions for the analysis of provinces were the mean maximum temperature (F = 72.88; P = 0.003) and the mean monthly temperature (F = 66.34; P = 0.001) in Niassa province explaining 100% of the variance (χ^2 = 27.66; df = 6; P = 0.0001) and classifying all districts correctly; in Cabo Delgado province the difference between daytime and night-time temperatures (F = 9.79; P = 0.010) and altitude (F = 9.64; P = 0.001) explaining 98.9% of variance (χ^2 = 23.01; df = 6; P = 0.001) and classifying 90.0% of districts correctly; in Nampula province the altitude (F = 4.31; P = 0.045) was capable of explaining 100% of the variance (χ^2 = 9.94; df = 4; P = 0.001) and classifying 41.7% of the districts correctly; and in Zambezia province the mean maximum temperature (F = 28.50; P = 0.0001) was able to explain 100% of the variance (χ^2 = 20.97; df = 4; P = 0.001) and classifying 90.9% of districts correctly.

Discussion

The climadiagram analysis of the districts shows the wet season (surplus water) to generally last from November to April/May, increasing the breeding sites for the mosquito vector, as demonstrated in endemic areas of Kenya, where *C. quinquefasciatus* thrives in a variety of aquatic habitats including rice fields, canals, seepage areas, ditches, marshes, pits and temporary pools (Muturi et al., 2008). Moreover, since it is well-known that LF transmission occurs within the temperature range of 22-30 °C, the permanently stable temperature of 20-25 °C enables the vector to transmit the *W. bancrofti* infection over the entire year in practise.

The LFRI and Wb-bsI results showed a high probability of transmission in the study area, agreeing with the expected risk when considering the influence of available environmental variables as demonstrated in other endemic areas. For example, for temperature, surface moisture and standing water (Thompson et al., 1996) and with respect to land cover, the normalized difference vegetation index (NDVI) and moisture index (Hassan et al., 1998) as well as temperature and rainfall in the African continent including the Nile delta (Lindsay and Thomas, 2000). It has also been shown for altitude, temperature, rainfall, soil type and relative humidity in India (Sabesan et al., 2006). However, in some districts, the prevalence rates reported disagree entirely, and the discriminant analysis did not correlate either, suggesting that other factors may influence the presence of the vector, its development and LF transmission capability. These results agree with other studies emphasising the important influence of social as well as other environmental vari-

Table 3. Canonic discriminant functions for LF prevalence, considering the 40 analysed districts.

Discriminant function	% of variance	Canonic correlation	χ^2	df	P
D_1= -0.191A + 0.884MaxMT	76.5	0.861	69.39	10	<0.0001
D_2= 1.172A + 0.793MaxMT	23.5	0.864	22.06	4	<0.0001

A: altitude; MaxMT: maximum mean temperature; df: degrees of freedom ables, some of which are related to living conditions, sanitation and migration, contributing to the urbanization of LF in endemic areas (Sherchand et al., 2003; Bonfim et al., 2011). Others are related to water-resource development and management, ecological transformation and modernization of agriculture in the rural areas as well as rapid and uncoordinated urban development favouring the increase of *C. quinquefasciatus* breeding sites and thus leading to an augmented LF transmission risk (Erlanger et al., 2005). Moreover, the classification of districts in relation to LF prevalence rates provided by discriminant analysis, especially in Nampula, a province with particularly high prevalence, did not coincide with reported values. This reinforces the hypothesis that other factors, not included in the analysis, also influence transmission and that the same factors may exert a positive or negative influence in different districts, as each of them may interact with other factors at the local scale. In addition, the poverty/development index, the types of local crops and particularly the extension of the rice pads are potential variables not considered in the study but likely to influence LF transmission in at least the erroneously classified districts.

Conclusions

The constant temperature over almost the entire year, altitude, economic conditions and the agricultural system of production are crucial factors favouring abundance and permanence of the vector in the study area.

Environmental and socio-economic conditions of the population facilitate the permanence of parasite infection in communities, thus exercising a negative impact on public health and the economic development of the area.

Both the parasite and the vector are favoured in the zones closest to the tropical parts of the country, while the temperature tends to be colder and thus does not benefit the permanence of the parasite, although the vector is present, in zones further away.

The presence and extension of rice pads and the population poverty/development index have to be considered as risk factors with respect to LF in Mozambique.

References

Bonfim C, Alves A, Costa TR, Alencar F, Pedroza D, Portugal JL, Medeiros Z, 2011. Spatial analysis and privation index to identify urban areas with a high risk of lymphatic filariasis. Trop Med Int Health 16, 748-755.

Erlanger TE, Keiser J, Caldas de Castro M, Bos R, Singer BH, Tanner M, Utzinger J, 2005. Effect of water resource development and management on lymphatic filariasis, and estimates of population at risk. Am J Trop Med Hyg 73, 523-533.

FAO, 2000. World-wide agroclimatic database. Environment and Natural Resources. Working Paper No. 5, FAO, Agrometeorology Group, Rome.

Fuentes MV, 2006. Remote sensing and climate data as a key for understanding fasciolosis transmission in the Andes: review and update of an ongoing interdisciplinary project. Geospat Health 1, 59-70.

Harb M, Faris R, Gad AM, Hafez ON, Ramzy R, Buck AA, 1993. The resurgence of lymphatic filariasis in the Nile delta. Bull World Health Organ 71, 49-54.

Hassan AN, Beck LR, Dister S, 1998. Prediction of villages at risk for filariasis transmission in the Nile delta using remote sensing and geographic information system technology. J Egypt Soc Parasitol 28, 75-87.

Hunter JM, 1992. Elephantiasis: a disease of development in north east Ghana. Soc Sci Med 35, 627-645.

IFAD (International Fund for Agricultural Development), 2008. Rural poverty in Mozambique. Available at: http://www.rualpovertyportal.org/web/guest/country/home/tags/mozambique (accessed on May 2010).

INE (Instituto Nacional de Estadística), 2008. Base de Dados do Censo 2007. Available at: http://www.ine.gov.mz (accessed on May 2010).

Lindasy SW, Thomas CJ, 2000. Mapping and estimating the population at risk from lymphatic filariasis in Africa. Trans R Soc Trop Med Hyg 49, 37-45.

MAE (Ministerio da Administração Estatal), 2005. Perfis distritais, Ed. Ministerio da Administração Estatal, Maputo, 53 pp.

Malone JB, Gommes R, Hansen J, Yilma JM, Slingenberg J, Snijders F, Nachtergaele F, Ataman E, 1998. A geographic information system on the potential distribution and abundance of *Fasciola hepatica* and *F. gigantica* in East Africa based on Food and Agriculture Organization databases. Vet Parasitol 78, 87-101.

Malone JB, Poggi E, Igualada FJ, Sintasath D, Ghebremeskel T, Corbett JD, McCarroll JC, Chinnici P, Shililu J, McNally K, Downer R, Perich M, Ford R, 2003. Proceedings International Geoscience and Remote Sensing Symposium (IGARRS), 1000-1003.

Malone JB, Williams TE, Muller RA, Geaghan JP, Loyacano AF, 1987. Fascioliasis in cattle in Louisiana: development of a system to predict disease risk by climate, using the Thornthwaite water budget. Am J Vet Res 48, 1167-1170.

MISAU (Ministerio da Saúde de Moçambique), 2009. Available at: http://www.misau.gov.mz/pt/epidemias_endemias/ (accessed on May 2010).

Mudenda NB, Malone JB, Kearney MT, Mischler PD, Nieto Pdel M, McCarroll JC, Vounatsou P, 2012. Modelling the ecological niche of hookworm in Brazil based on climate. Geospat Health 6, S111-S123.

Muturi E, Mwangangi J, Shililu J, Jacob BG, Mbogo C, Githure J, Novak R, 2008. Environmental factors associated with the distribution of *Anopheles arabiensis* and *Culex quinquefasciatus* in a rice agro-ecosystem in Mwea, Kenya. J Vector Ecol 33, 56-63.

Sabesan S, Raju HKK, Srividya A, Das PK, 2006. Delimitation of lymphatic filariasis transmission risk areas: a geo-environmental approach. Filaria J 5, 12-17.

Sherchand JB, Obsomer V, Das Thakur G, Hommel M, 2003. Mapping of lymphatic filariasis in Nepal. Filaria J 2, 7-15.

Taylor MJ, Hoerauf A, Bokarie M, 2010. Lymphatic filariasis and onchocerciasis. Lancet 376, 1175-1185.

Thompson DF, Malone JB, Harb M, Faris R, Huh OK, Buck AA, Cline BL, 1996. Bancroftian filariasis distribution and diurnal temperature differences in the Southern Nile delta. Emerg Infect Dis 2, 234-235.

Valencia-López N, Malone JB, Carmona CG, Velásquez LE, 2012. Climate-based risk models for *Fasciola hepatica* in Colombia. Geospat Health 6, S67-S85.

WHO, 1997a. Lymphatic filariasis: reasons for hope. Geneva: World Health Organization.

WHO, 1997b. Lymphatic filariasis elimination. Report of a meeting of the principals for the further enhancement of public/private partnership. Geneva: World Health Organization.

WHO, 2011. Monitoring and epidemiological assessment of mass drug administration in the global programme to eliminate lymphatic filariasis: a manual for national elimination programmes. Geneva: World Health Organization.

Yang GJ, Gemperli A, Vounatsou P, Tanner M, Zhou XN, Utzinger J, 2006. A growing degree-days based time-series analysis for prediction of *Schistosoma japonicum* transmission in Jiangsu province, China. Am J Trop Med Hyg 75, 549-555.