Integration of Demographic, Climate and Epidemiological Factors in the Modeling of Meningococcal Meningitis Epidemic Occurrence in Niger[1]

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Abstract

Meningitis outbreaks in the African Belt have been associated with climatic, epidemiological, and demographic and socioeconomic conditions. This paper presents preliminary results of an ongoing project looking at quantify the relative influence of these different factors in Niger, part of Africa's Meningitis Belt. For that, we integrated climate, demographic and epidemiological data in a single, district-level database, and analyzed these data using exploratory data analysis and regression techniques.

Introduction

Meningococcal meningitis presents its highest activity and toll on populations in Sub-Saharan Africa, in an area determined by its environmental conditions and designated as the "meningitis belt" stretching from Senegal in the west to Ethiopia in the east (fig.1). In this belt, the highest disease morbidity is recorded during the dry season, when climatic and living conditions (e.g. crowding) and population movements favor increased disease transmission, resulting in annual incidence rates that can reach 1,000 cases per 100,000 inhabitants.

Outbreaks of Meningococcal epidemics have long been related to environmental conditions such as dry and dusty environment (Lapeyssonie 1963), and the spatial risk distribution based on environmental suitability factors such as absolute humidity, absorbing aerosols, rainfall and land-cover has been modeled (Molesworth et al. 2003; Savory et al. 2006, fig 1).

However, because meningitis is a human-to-human spread disease, it is relevant to bring other factors such as demography and immunological state to play. The combination of all the relevant information will contribute to the development of a comprehensive decision support system for meningitis control to be used by international and national organizations.

This paper presents preliminary results of an ongoing project looking at quantify the relative influence of these different factors in Niger, part of the Africa meningitis belt. The integration of climate, demographic

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and epidemiological data in a district-level database was the first step. In the second stage (currently underway), we analyze these data using exploratory data analysis and regression techniques.

Background

Population dynamics

The particular spatial distribution and concentration of large-size epidemics suggests that "demographic risk factors are important in the development of larger disease outbreaks" (Pollard and Maiden 2003). Population surfaces displaying total population counts, density or both provided the denominators for calculating the incidence of the disease (Thomson et al. 2006). Population density is likely related to the spread of the disease, while a rural or urban residence generally marks differences in terms of access to health care, information and resources (Balk et al. 2003).

Population crowding and interaction may act as proxies for the likelihood of an individual being within range of transport distance. Crowdedness (in dwellings and social gatherings) and socioeconomic status are regularly counted among social and demographic risk factors (WHO and UNICEF 2008; Hodgson et al. 2001; Trotter and Greenwood 2007; WHO 2005).

Exposure to smoke from cooking fires and close contact with a case has also been mentioned (Hodgson et al. 2001), introducing a potential gender differences because women are more likely to cook or to be caregivers. Age structure could act as proxy for vulnerability, immune status and exposure to transmission, since the incidence of the disease varies by age. Although age distribution of incidence during epidemics is broad (WHO 1998), people below age 30 are considered the population more at risk and the target for emergency reactive vaccination (Moore 1992; Leimkugel et al. 2007; Sultan et al. 2005).

Different forms of population mobility (nomads' north-south annual movements, seasonal labor migration, rural-urban migration with occasional visits to the place of origin, refugees) have been mentioned as potentially significant factors in disease transmission and the spread of epidemics (WHO 1998; Memish 2002; Molesworth et al. 2003; Sultan et al. 2005; Yaka et al. 2008; WHO and UNICEF 2008) The comparison of the calendar of intra-annual, seasonal and other temporary population mobility with seasonal and a-periodic environmental anomalies could inform the modeling of first case, onset and offset of meningitis. Acting as carriers, movers put in contact areas and populations with different demographic, socioeconomic and especially epidemiological characteristics (Trotter and Greenwood 2007). It has been suggested that the classical cycle of outbreaks every 8-12 years has been replaced by shorter and irregular intervals in areas of extensive communications and mixing of populations (WHO 1998:8). In particular, pilgrimages have been linked to initiation and diffusion of the W135 strain (Gold 2003; AA 2002; Taha et al. 2000; Moore 1992; WHO 2005). Just to give an idea of the magnitude of these movement , the average numbers of pilgrims from Nigeria to Mecca in the 1997-1999 period was estimated in 20,737 (Bianchi 2004)

Environmental Factors

The meningitis belt roughly coincides with the Sahel, characterized by high seasonality of rainfall, with one rainy season occurring in July to September, when southwesterly monsoon winds bring moisture from the nearby Atlantic into the continent. The remaining of the year the Sahel is dominated by dry northeasterly winds blowing from the Sahara (Harmattan) and generally dusty conditions (fig. 3) The seasonal cycle can be approximated as a north-south displacement of the convergence between the

Harmattan and monsoon flows (roughly coinciding with the location of the rainbelt), with northernmost location of this convergence during the rainy season over the Sahel.

The prevailing humidity during the rainy season is not suitable for meningitis outbreaks and the meningitis season usually ends with the arrival of humid air masses in April-May, prior to the establishment of the rainy season. The onset of the meningitis season occurs after the end of the rainy season with first case typically appearing in October. The strong increase in disease occurrence in Mali has been observed around week 6 of the year (February) and related to the southernmost location of the convergence between the Harmattan and Monsoon winds (Sultan et al. 2005).

The timing of the interannual variability of the onset of the meningitis season in Mali has been related to interannual variations of the north-south movements of the wind pattern (Sultan et al. 2005). This in turn can be related to the large scale climate conditions which, in the tropics, are driven mostly by the Sea Surface Temperatures and are potentially predictable by climate seasonal forecasts. However, until now very little attention has been given to the seasonal forecasts during the dry season, most of the efforts being concentrated on assessments of the skill in predicting the characteristics of the rainy season for obvious food-security reasons.

The relationship between meningitis outbreaks and dust although mentioned in literature (Thomson et al., 2006) is not fully understood and requires further investigation and quantification. Another factor thought to be important is the sporadic rain episodes during the dry season which frequency increases towards the rainy season. These episodes are related to specific atmospheric circulation patterns involving interactions with the extratropics (Khelifa and De Felice, 1997). They may reduce the meningitis risk by bringing moister air into the region and depositing aerosols. Their role and predictability have to be fully assessed.

Immunological State of the Population

The natural exposure to the disease confers a 100% immunity for ca 4 years, decreases during the fifth year and is zero in the sixth year (Moore 1992; Riou et al. 1996). Field studies report that 50 to 100% immunity level in general population following an epidemics, either by natural exposure or vaccination (Pinner et al. 1992; Moore 1992; Spiegel et al. 1993; Lengeler et al. 1996; Varaine et al. 1997). Thus the recent epidemic history has to be carefully taken into account in any modeling as well as in the development of Early Warning System

Data and methods

The selection of Niger as case study was based on the availability of time series of epidemiological data recording cases of meningitis at the district level since 1986. WHO's definition of an outbreak of meningitis follows specific rules based on total population of the district. For districts where the population is less than 30,000, the threshold is 5 cases in 1 week or doubling of the number of cases in a 3-week period and case-by-case analysis. For districts with a population greater than 30,000, the threshold is defined as (i) no epidemic for 3 years and vaccination coverage <80% or (ii) alert threshold crossed early in the dry season1, i.e. before March.

The epidemiological data were integrated with climate and demographic information, which had to be down- or re-scaled to the district level to match the meningitis data. A list of data sources with their main characteristics is provided in Table 1.

Analysis

We are now in the process of analyzing this integrated database. In a first step, we are using standard exploratory data analysis techniques to test the existence of relationships among the variables.

As expected, the incidence of meningitis varies along the year, from year to year and across districts (fig. 4). A preliminary analysis of the mean seasonal cycle of meningitis in all the districts in Burkina Faso, Mali and Niger (fig. 5) shows that the epidemic season tends to start earlier in the southern districts progresses northward.

Among the factors potentially explaining this somehow counter-intuitive result (the dry season starts earlier and lasts longer in the northern districts) are: population density (higher in the south) and higher dust concentrations during the dry season, highlighting the absolute necessity of simultaneously exploring the effects of demography and environment as risk factors.

After selecting the most relevant risk factors, we will build a Generalized Linear Model (Held et al. 2005)to predict the meningitis risk (meningitis outbreaks, incidence of meningitis, and number of meningitis cases) at different time leads (from forecasting the risk for the next week to the forecast of the risk for the whole season).

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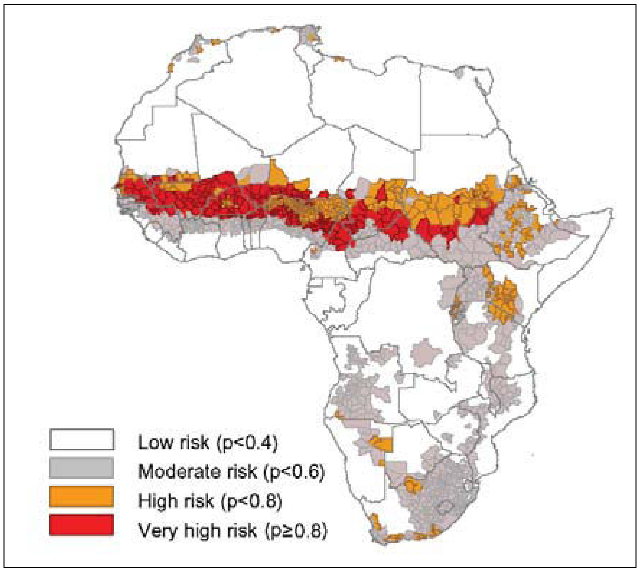
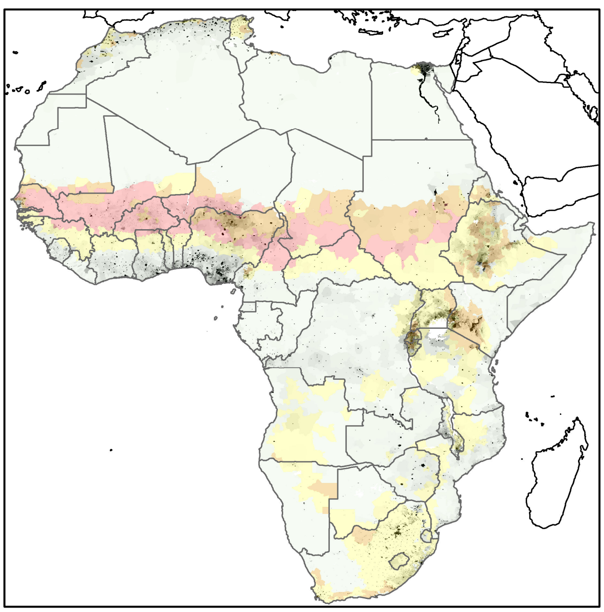
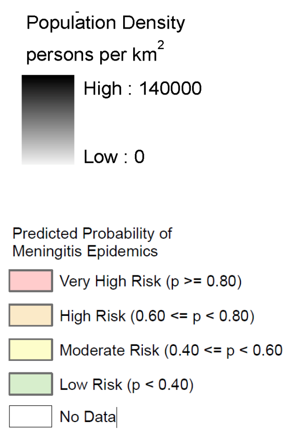
Fig.1: Risk map of meningitis epidemic outbreaks based on environmental variables (absolute humidity profile and land-cover type)



Source: Molesworth et al. 2003:1289

Fig. 2: Population density in meningitis risk areas of Africa





Sources: elaborated by CIESIN, based on Molesworth et al. 2003; and Center for International Earth Science Information Network et al. 2004

Fig. 3: Schematic meridional cross section of atmospheric circulations over West Africa showing the northward transport of biomass burning aerosol in warm, ascending air (red arrows) and the westward/southward transport of mineral dust in a cooler airflow (blue arrows). The ''Harmattan front'' is shown by the solid line which marks the boundary between the two air masses with arrows representing mixing of the dust with the biomass burning smoke (Haywood et al., 2008).

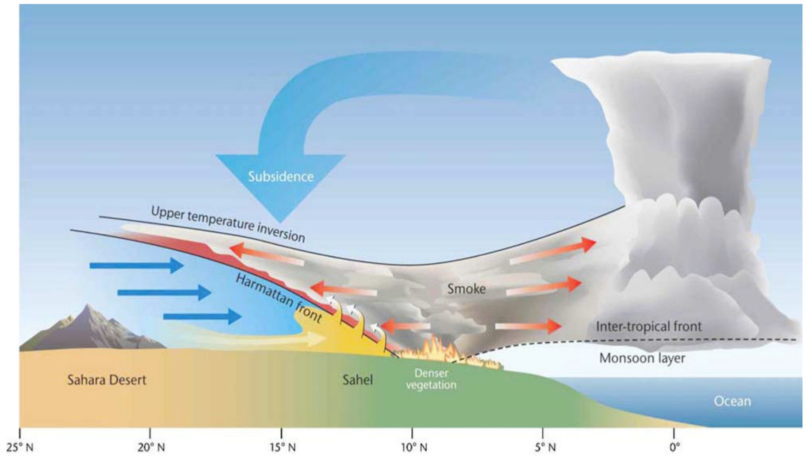
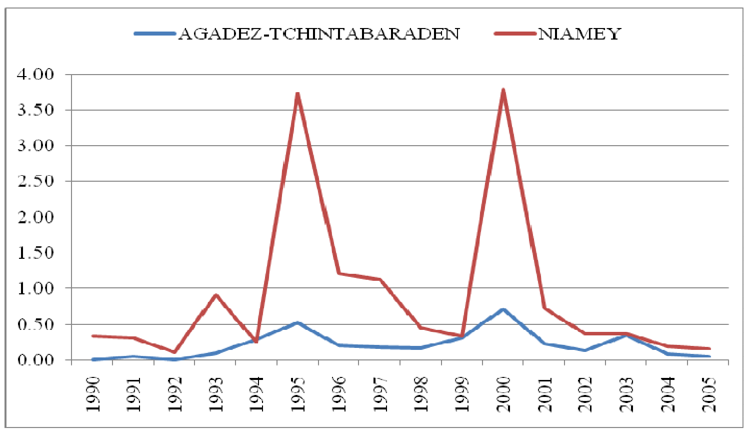
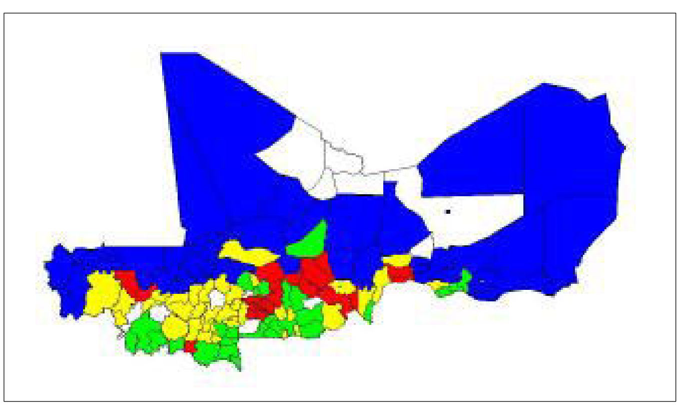


Fig 5: Incidence of meningitis in Niger, 1990-2005, selected districts



Source: own elaboration based on epidemiological data from WHO-Niger

Fig. 5: Cluster analysis of weekly meningitis incidence at the district level in Mali, Burkina Faso and Niger over the period 1996-2005. Left: spatial distribution of clusters. Right: associated mean seasonal cycle



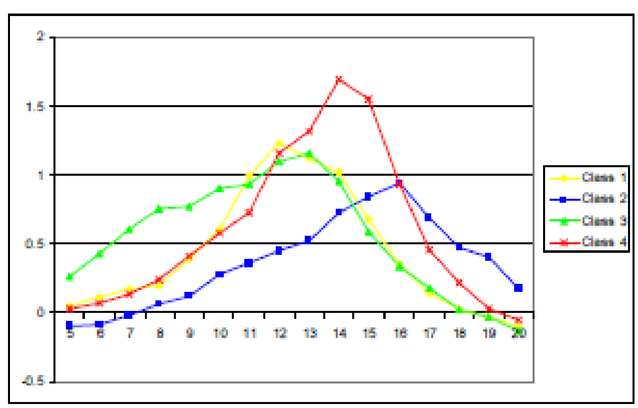


Table 1: Data sources characteristics

Variable category	Variable name	Source of the data	Origin of the data	Time resolution	Spatial resolution	Time coverage	Spatial coverage
Epidemiological	Incidence of meningitis	Ground	WHO routine surveillance	Week	District	Dec 1985 - May 2008	All districts, Niger
Immunological state of the population	Recent history of outbreaks	Ground	WHO routine surveillance	Week	District	Dec 1985 - May 2008	All districts, Niger
Aerosol/Dust	Absorption Angstrom Exponent (α)	Satellite	AERONET[i], NASA	Daily	Single point	Oct 1995- June 2009	Banizoumbou, Niger
		Satellite	MISR[ii], NASA	Daily	0.25x0.25	Apr 2000-Apr 2009	Africa north of the Equator Longitude: [74.875W,64.875E]; Latitude: [0.125N,34.875N]
	AOD[iii]/ AOT[iv]	Satellite	AERONET, NASA	Daily	Single point	Oct 1995- June 2009	Banizoumbou, Niger
		Satellite	MISR, NASA	Daily	0.25x0.25	Apr 2000-Apr 2009	Longitude: [74.875W,64.875E]; Latitude: [0.125N,34.875N]
		Model	Mineral Dust aerosol model GISS, NASA: Global Climate Model E	Hourly and Monthly	Horizontal: 144x90 grid cells (2.5°x2°) Vertical : Total over troposphere	1984-2009	Global
	Dust fraction: Total, large, medium, small	Satellite	MISR, NASA	Daily	0.25x0.25	Apr 2000-Apr 2009	Longitude: [74.875W,64.875E]; Latitude: [0.125N,34.875N]
	Dust surface concentration	Model	Mineral Dust aerosol model GISS[v], NASA: Global Climate Model E	Hourly and Monthly	Horizontal: 144x90 grid cells (2.5° x 2°) Vertical : surface layer	1984-2009	Global
	Visibility	Ground	Met Station	Daily	Single point	1995-2009	Niamey, Niger
Wind	Wind speed	Ground	Met Station	Daily	Single point	1995-2009	Niamey, Niger
		Model	Seasonal forecast	Daily and monthly	Vertical: near surface (2m, 10m) and Plevels (925, 950, 850 etc) Horizontal: ECHAM 4.5 T42: 2.5°x2.5°		
		Model	NCEP/NCAR Reanalysis	Daily and monthly	Vertical: 1.'diagnostic' or 'near-surface' (also 'top') variables: one level, specified (surface, 2m, 10m etc) 2.'intrinsic' variables: across the atmospheric depth, Horizontal: 1. diagnostic ' variables : 1.875° (long)x2.5° (lat). 2.'intrinsic' variables 2.5°x2.5°on specified Pressure levels (950hPa, 500hPa, sea level	1948 -present (last week for daily, last month for monthly)	

					pressure) or total atmospheric column		
	Wind direction	Model	Seasonal forecast	Daily and monthly	Vertical: near surface (2m, 10m) and Plevels (925, 950, 850 etc) Horizontal: ECHAM 4.5 T42: 2.5°x2.5°		
		Model	NCEP/NCAR Reanalysis	Daily and monthly	Vertical: 1.'diagnostic' or 'near-surface' (also 'top') variables: one level, specified (surface, 2m, 10m etc) . 2.'intrinsic' variables: across the atmospheric depth, on specified Pressure levels (950hPa, 500hPa, sea level pressure) or total atmospheric column Horizontal: 1. diagnostic ' variables : 1.875° (long)x2.5° (lat). 2.'intrinsic' variables 2.5°x2.5°	1948 -present (last week for daily, last month for monthly)	
Humidity	Dew point	Ground	Met Station	(unitless) ordered (1.) to (137231.)	Single point	(unitless) ordered (1.) to (137231.)	Niamey, Niger
	Humidity	Model	Seasonal forecast	Daily and monthly	Vertical: near surface (2m, 10m) and Plevels (925, 950, 850 etc) Horizontal: ECHAM 4.5 T42: 2.5°x2.5°		
		Model	NCEP/NCAR Reanalysis	Daily and monthly	Vertical: 1.'diagnostic' or 'near-surface' (also 'top') variables: one level, specified (surface, 2m, 10m etc) 2.'intrinsic' variables: across the atmospheric depth, on specified Pressure levels (950hPa, 500hPa, sea level pressure) or total atmospheric column Horizontal: 1. diagnostic ' variables : 1.875° (long)x2.5° (lat). 2.'intrinsic' variables 2.5°x2.5°	1948 -present (last week for daily, last month for monthly)	
Temperature	Temperature	Model	Seasonal forecast	Daily and monthly	Vertical: near surface (2m, 10m) and Plevels (925, 950, 850 etc) Horizontal: ECHAM 4.5 T42: 2.5°x2.5°		
		Model	NCEP/NCAR Reanalysis	Daily and monthly	Vertical: 1.'diagnostic' or 'near-surface' (also 'top') variables: one level, specified (surface, 2m, 10m etc) 2.'intrinsic' variables: across the atmospheric depth, on specified Pressure levels (950hPa, 500hPa, sea level pressure) or total atmospheric column Horizontal: 1. diagnostic ' variables : 1.875° (long)x2.5° (lat). 2.'intrinsic' variables 2.5°x2.5°	1948 -present (last week for daily, last month for monthly)	
Rainfall	Rainfall estimates	Satellite	TRMM[i], NASA	3 hours	0.25x0.25		
Demography	Population density	Ground	GPW3 (GriddedPOP)	5 years	0.25x0.25	1990, 1995, 2000 (estimates), 2005, 2010, 2015 (projections)	Africa north of the Equator Niger
	Population count	Ground	GPW3 (GriddedPOP)	5-year	0.25x0.25	1990, 1995, 2000 (estimates), 2005, 2010, 2015 (projections)	Africa north of the Equator Niger
	Urban and rural population count	Ground	GRUMP GriddedURBAN)	Yearly	0.25x0.25	1990-2000	Africa north of the Equator Niger

	Urban and rural population density	Ground	GRUMP (GriddedURBAN)	Yearly	0.25x0.25	1990-2000	Africa north of the Equator Niger
	Sex and age structure	Ground		5-year	Country	1950-2005	Niger
	Population count, density, sex and age structure, migration	Ground	Niger statistical office	10 years	District	2001	Niger

Source: NASA-ROSES project

[1] AErosol RObotic NETwork
[1] Multiangle Imaging Spectroradiometer
[1] Aerosol Optical Depth
[1] Aerosol Optical Thickness
[1] Goddard Institute for Space Studies