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

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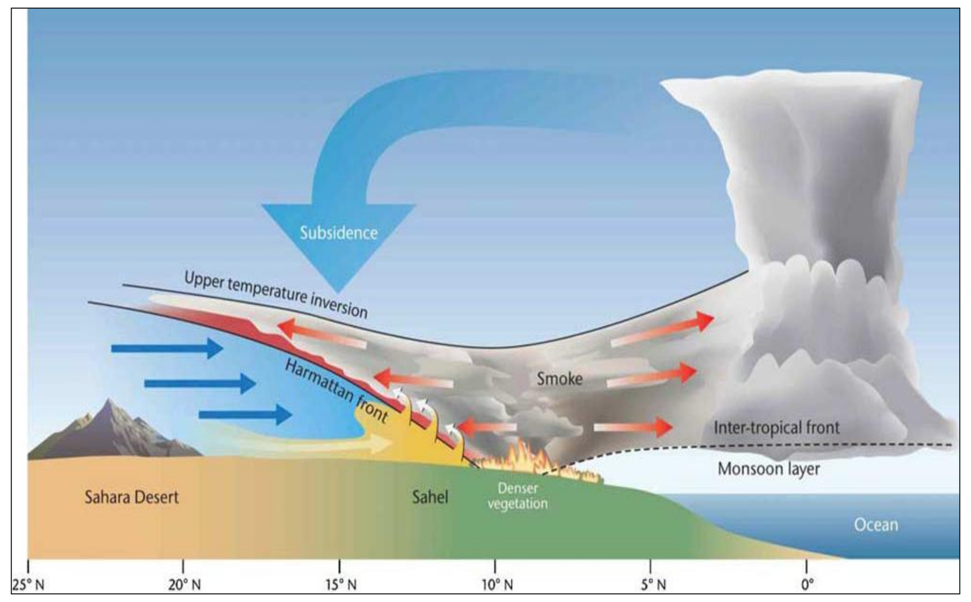
❑ Meningococcal meningitis (MM) presents its highest activity and toll on populations in Sub-Saharan Africa, in an area determined by its environmental conditions and designated as the **"meningitis belt"** stretching from Senegal in the west to Ethiopia in the east. It affects close to 400 million people, and annual incidence rates can reach 1,000 cases per 100,000 people.

❑ The disease has a tremendous economic impact, the burden estimated to be more than $11 million/year in diagnostic, tests and case treatment costs.

Climate, Seasonality, Distribution and Density

❑ Outbreaks of Meningococcal epidemics have been related to environmental conditions such as dry and dusty environment (Lapeyssonie 1963) (Fig. 1)



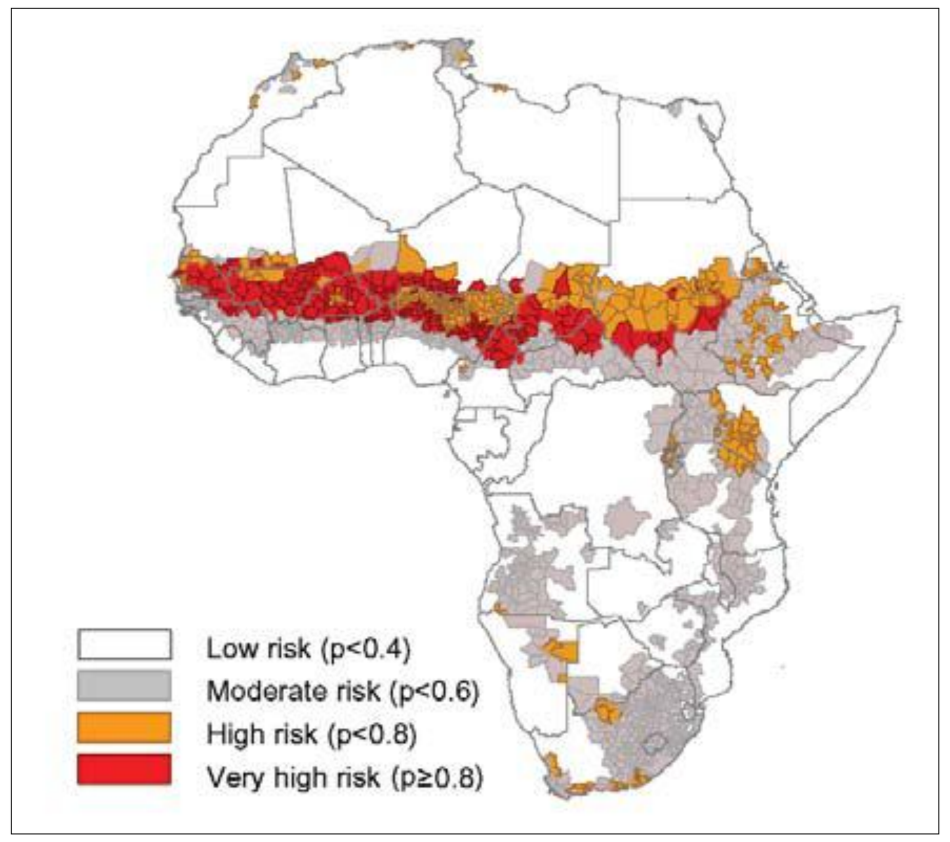
Source: Haywood et al., 2008

Fig. 1: 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.

❑ 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 (Sultan et al. 2005).

❑ 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.2)

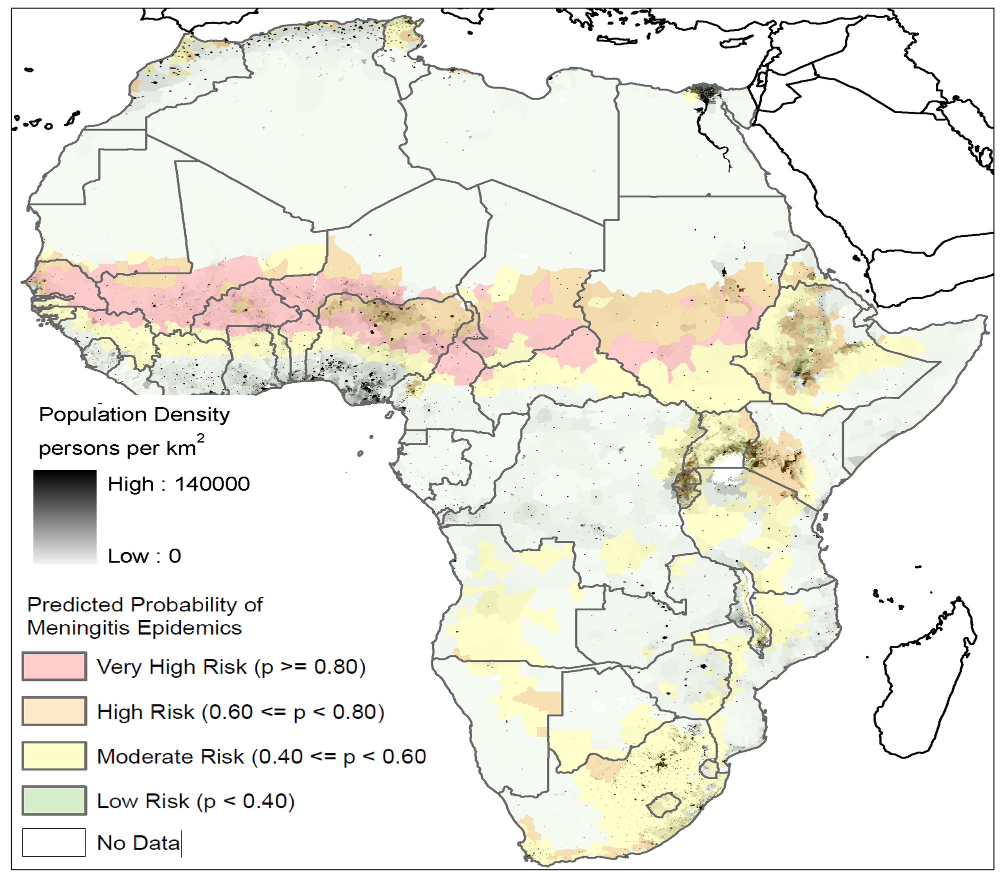
Fig.2: Risk map of meningitis epidemic outbreaks based on environmental variables (absolute humidity profile and land-cover type)



Source: Molesworth et al. 2003:1289

❑ However, it has been suggested that other factors need to be incorporated in the modeling of meningitis occurrence (YAka et al. 2008), such as as demography (population size, desnsity, age structure) and immunological state of the population.

Fig. 3: 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)

❑ 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 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).

❑ Finally, population surfaces displaying total population counts, density or both provided the denominators for calculating the incidence of the disease (Thomson et al. 2006).

Data and Methods

❑ Niger was selected as case study because of the availability of time series of epidemiological data recording cases of meningitis at the district level since 1986.

❑ We integrated climate, demographic and epidemiological data in a single, pooled, district-level database.

❑ Then, we fit a multiple linear regression model using demographic, geographic and atmospheric independent variables, and an epidemiological dependent variable at district level.

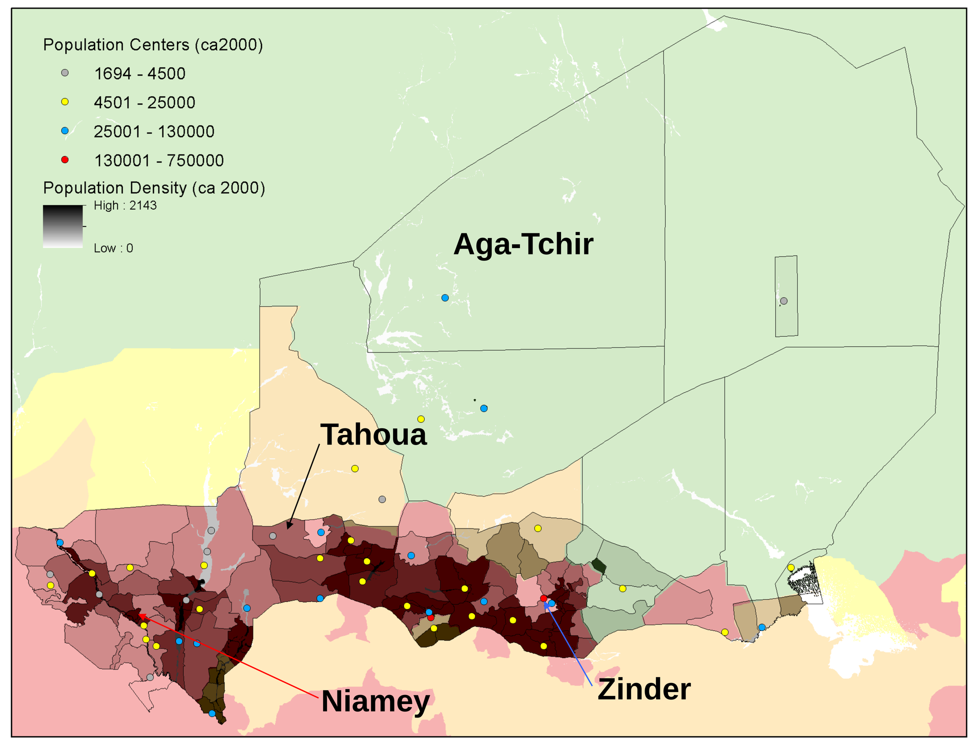
❑ Dependent variable: weekly number of cases at district level transformed into incidence (cases/100,000) for 1986-2008 period; 38 districts initially. Frequency of occurrence of epidemics=number years epidemics occurred/total number of years in the record for a given district. A year is defined as epidemic if the incidence crosses the WHO operational threshold of 10cases/100,000 in at least one week

❑ Predictors: *Demographic variables*: log10(Total Population), log10(Population density), percentage urban population, percentage urban area; *Geographic variables*: district area, latitude and longitude of district centroids; *Atmospheric variables*: January to March averages for zonal and meridional wind components, temperature and specific humidity at 925 hPa level from NCEP Reanalysis (values re-scaled at district level)

Results

❑ Overall climate conditions in Niger are adequate for meningitis outbreaks. These environmental conditions interact with demographic conditions as by population distribution, size and density (fig 4).

Fig. 4: Meningitis risk zones, population density and population centers in Niger's districts, ca 2000. A darker shadow indicates higher population density



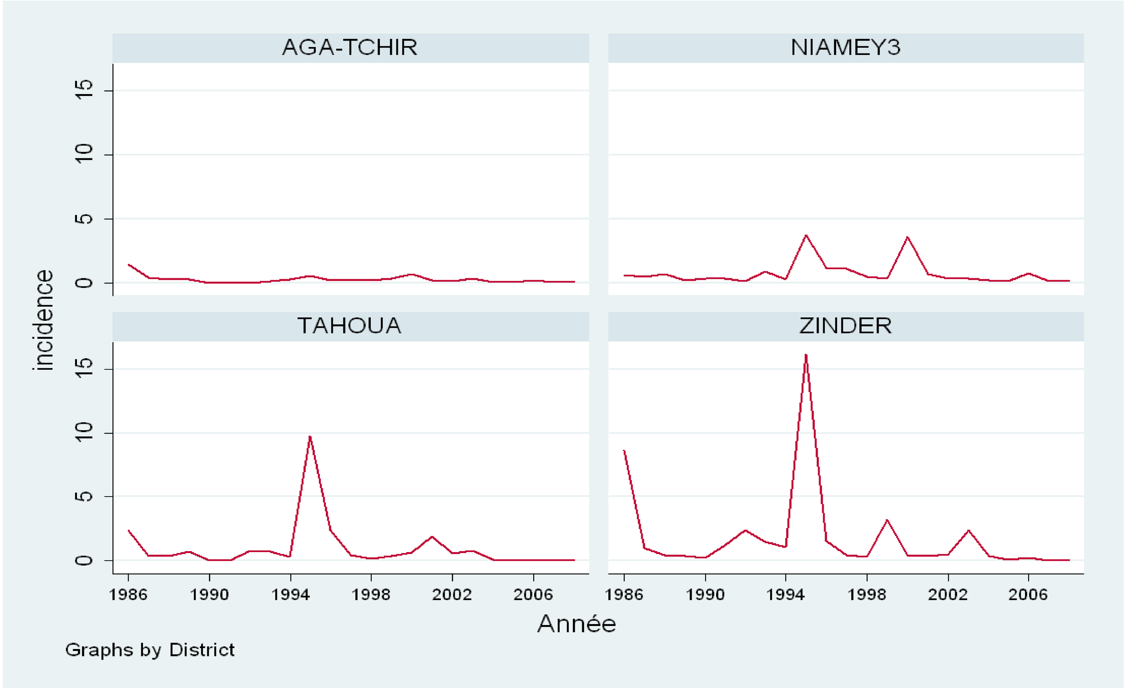
Sources: own elaboration based on Molesworth et al. 2003; and CIESIN et al. 2004

❑ The incidence of meningitis varies along the year, from year to year, and across districts (fig. 5).

❑ In general, incidence levels in Niger follow Molesworth et al.'s risk zones, but not necessarily density. Tahoua and Zinder display higher incidence levels than Niamey (the nation capital), even when Niamey's density is larger.

❑ Incidence is lower in the North.

Fig. 5: Incidence of meningitis in selected Niger's districts, 1986-2006



Sources: own elaboration based on Niger's Epidemiological Data

❑ Initial examination of relationships between the frequency of epidemics and each independent variable was done via scatterplots and linear correlation analysis

❑ Best relationship was found to be with log10(popdensity)

2 districts were left out in subsequent analysis:

- Niamey: totally urban, better access to health care, potentially different reporting system
- Bilma, very rural, low population density, some issues in the time series.

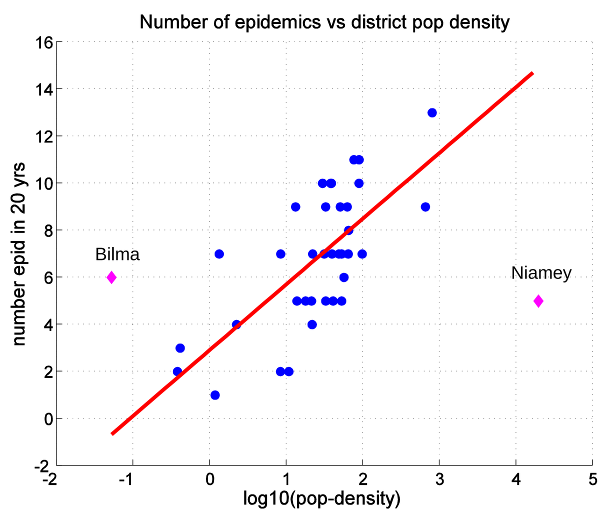


Fig. 6: Scatter plot: population density (log) and epidemic frequency

❑ Stepwise selection of best multiple regression model using all 11 predictors was performed.

❑ Best model obtained using log10(pop density), meridional wind at 925 and log10(total population) (Fig. 7)

*Epidemic frequency = 26.5+2.35*log10(distr_pop_den)+1.72*mer_wind-4.26*log10(distr_pop)*

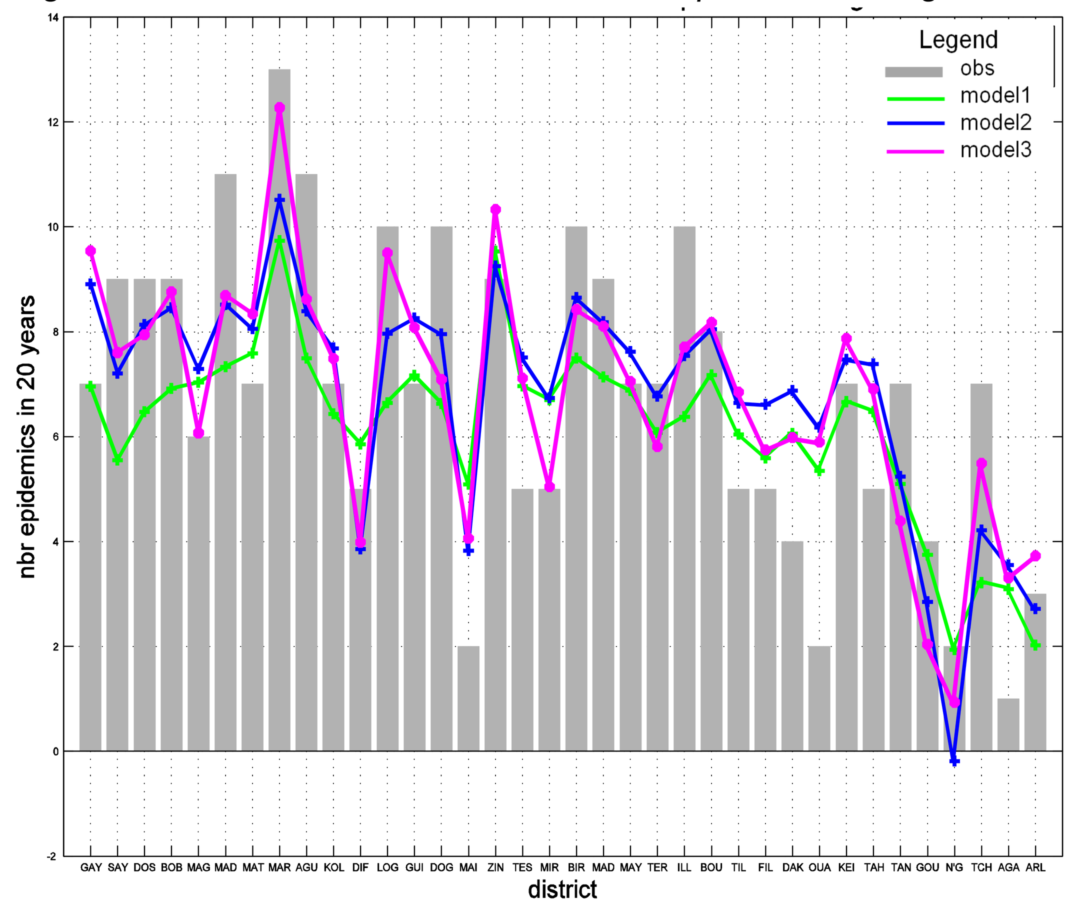
Fig. 7: Results of multivariate lineal regression

Predictor	Coef	Std err	p
Distr pop den	2.3452	0.5158	0.0001
Distr pop	-4.2558	1.6350	0.0139
Mer wind925	1.7216	0.4774	0.0010

❑ Fig. 8 shows the comparison between observations and models:
Model1: one predictor = (log10(popdensity)
Model2: 2 predictors = Log10(pop density) and meridional win
Model3: all 3 predictors

❑ However, the modest improvement in r (0.69, 0.76 and 0.8) and the value of RMSE (resp. 2.1, 1.93 and 1.79) indicate that the model is not significantly improved by adding predictors 2&3, highlighting that in Niger, population density is the main determinant of the frequency epidemic outbreaks

Fig. 8: Observed and modeled number of epidemics in Niger districts



Preliminary conclusions

❑ The inclusion of demographic factors (population size, distribution and density) in the modeling of spatial distribution of meningitis outbreaks in Niger proved to have a significant effect.

❑ In next steps, we will incorporate age and sex structure, and population mobility.

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