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Season-Smart: How Knowledge of Disease Seasonality and Climate Variability Can Reduce Childhood Illnesses in Mali

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Introduction

Seasonal variations in temperature and rainfall impacts family well-being through its effects on water resources, food production, and disease transmission[1-4], especially in the Sahel, a stretch of land squeezed between the Sahara desert and the savannah, where a long history of droughts and related famines have been catastrophic. The Sahel's weather pattern comprises three seasons: cold and dry, hot and dry, hot and wet. In abnormal years, these seasons are accentuated with consequences for food production, water availability and disease transmission. It is well known that malaria is a seasonal disease whose transmission is further affected by climate variability; however, other major childhood illnesses such as acute respiratory infection (ARI) and diarrhea also have a seasonal component that is affected by climate variability. Therefore, a preventive public health program based on knowledge of the seasonality and prediction of climate anomalies can reduce the seasonal and climate-related peaks in susceptible childhood illnesses.

Malaria, which is transmitted by the female *Anopheles* sp. mosquito,[1, 2] is one of the major protagonists of childhood morbidity and mortality in Africa.[3] It has received the bulk of attention as a climate-related disease. Malaria transmission is seasonal, typically starting two months after the beginning of the rainy season, peaking two months after the rainfall peak and then tapering off to low or negligible transmission during the final months of the dry season.[2,4,5] Malaria transmission becomes endemic, i.e. year-round, where mosquito breeding sites and appropriate temperatures persist, e.g. irrigation sites.[6, 7] The groups most at risk for malaria are children under 5 years of age who have not yet developed immunity to the disease; women in their first pregnancy (who are at greater risk due to their nutritional status); and labor migrants from non-endemic zones.[5, 8, 9-14] Recent research has found increased malaria transmission during periods of climate variability, particularly in "fringe" zones, such as the East Africa highlands and Southern Africa.[10] In West Africa, survival probabilities for the 1-5 age bracket are significantly less for children living in areas with less than 2 mm average daily rainfall and very short growing seasons, where malnutrition and wasting are greater.[11,12]

The possibility of a climate-related increase in acute respiratory illnesses is suggested by the factors accelerating transmission of airborne infectious diseases. Low humidity and dust may damage the mucosal barrier, and/or inhibit its immune defense, increasing mucosal invasion and the risk of disease during the dry season. Meningitis, for example, has higher transmission rates in the cold, dry seasons following a period of negative precipitations and/or with exceptionally strong winter winds or *harmattan*.[13, 14] Indoor overcrowding during cold or dust storm periods may enhance the spread of airborne infections, including pneumonia and measles.[15-37 4, 16]Thus, in several settings ARI incidence is higher at the end of the rainy season and during the cold, dry months, probably reflecting the existence of multiple pathogens.[38-17]

The transmission of gastro-intestinal diseases also is affected by precipitation, rising during the wet season with the greater contamination of water sources by fecal material. There is seasonal variability in different forms of gastro-enteritis, with peaks in the rainy season.[17-23] Only a handful of studies have looked beyond this seasonal pattern to observe the relation between diarrhea, season, and climate variability.[48-24] Climate-related or seasonal diarrheal peaks also may be related to seasonal nutritional deficiencies, for both children and breastfeeding mothers.[18, 25-27]

This manuscript documents the seasonality of childhood illnesses for the district of Niono, in the Sahelian Mali, and proposes a "season-smart" forecast application for the three main childhood illnesses—malaria, measles, and acute respiratory infection.

Methods

Niono is located in the region of Segou, 330 km northeast of Bamako, Mali. Figure 1 and Table 1 show the location and characteristics of the six health zones described in this study: Nampala, Dogofry, and Sokolo in the Sahel as well as Boh, Siribala, and Pogo in the savanna. In 2002, the Niono Division des Services Socio-Sanitaires (DSSS) estimated the population of these 6 health zones at 83,151 inhabitants. This district has been selected because of the potential for variability in rainfall, temperature, and disease transmission. Niono affords the opportunity to study the impact of climate variability on health and population interactions in an irrigated zone, namely the 50,000 hectares managed by Office du Niger along the Canal du Sahel, which is supplied by the Niger River. These zones enhance the potential for this study to document a wider range of micro-climates that influence vector populations and disease transmission.

Malaria transmission occurs six months of the year in the Sudano-Sahelian zone of Niono. In the southern and irrigated regions of Niono parasite prevalence levels are 75% or higher and malaria is endemic. In the northern portions of the district, the malaria transmission is similar to the Sahelian semi-desert type, displaying a 4-month long transmission season and a parasite prevalence in the vicinity of 50%. The extreme northern part of the district borders the Saharan zone and belongs to the Sahelian malaria "fringe" where malaria is meso-endemic, with transmission occurring only 2 to 3 months per year and prevalence around 10%; however, climatic variations, e.g. pluviometric increases, may intensify transmission in these areas where malaria prevalence and immunity levels are normally low. Studies conducted by the Malaria Research Training Center (MRTC) show that biting and infection rates differed significantly between the irrigated and non-irrigated zones.[28, 29] Water management practices associated with irrigation further impact mosquito population growth.[30] Finally, the irrigated zone influences disease transmission through its impact on labor migrations, which introduce persons with differing levels of disease immunity into the population.[5 3 2,17 4,33,9 1] While the irrigated zones had higher man-biting rates, the mosquitoes had lower levels of vector human blood indices, due to the higher level of immunity among the population working in the irrigated zone or greater use of bed nets.[28]

The last decades have seen wide fluctuations in the rainfall, with negative anomalies for 10 of the 30 years and positive anomalies in 6 of the years. Anomalies of the same direction tend to be clustered in consecutive years, but there are often positive and negative anomalies succeeding each other, indicating a pattern of climatic events in both directions. Zonal rainfall data correlate highly with SST variations for both the Atlantic and Indian Oceans.[31] The rainfall data for 1995 to 2004—FEWSNet/CPC rainfall monitoring dataset—was assembled into a time-series. These data are estimates based on the Meteosat satellite imagery of cloud density coverage, prepared every ten days for each 2 km grid square. The latitude and longitude of each health area is noted in Table 1. Before conducting the analysis, the monthly standard deviation from the 10-year mean (1995-2004) were computed. Pluviometric anomaly variables were assigned to precipitation deviations greater than +1 SD or smaller than – 1 SD, based on the ten year mean for that health zone. If estimates were not prepared for a grid point for a particular ten-day observation due to excessive cloud cover, that value was treated as missing.

Incidence rates for malaria, measles, and ARI were estimated from monthly consultations at the community health center(CSCOM) in each of the six regions. These data were assembled from records kept at the 17 CSCOMs in Niono for 1996-2004. Although the health consultations for each age group, sex, and disease (>20) were recorded separately, only the data pertaining to children under age 5 (<1, 1-4; both male and female) for malaria, ARI, and diarrhea were employed in the analysis. The consultation rates (per 1000) were based on 2002 population estimates that the Division of Health and Social Services of Niono provided.

The "season-smart" forecast application relies on 1) the identification of seasonal patterns and on 2) the quantification of seasonal variability. In order words, once seasonality is established, further methods may be employed to allocate public health interventions to time periods before the seasonal peaks, shifting their implementation to a more cost-effective time period. Thus, the first step in developing the "season-smart" algorithm was to test the seasonality assumption. This was done with a Fourier transform procedure. [32] While seasonal or harmonic components appear as distinct spectral peaks, non-periodic variation is typified by the absence of any clear pattern, i.e. "noisy" spectral. The Fourier spectral analysis was performed for each disease, using the monthly consultation data for the 6 selected CSCOMs combined. Due to limited number of cases, Fourier transforms were performed on the disease time-series for all ages. The Tukey-Hamming spectral window (n=3) was used. The Fourier plots show spectral density on the y-axis and period (months) in the x-axis.

Once seasonality is established, i.e., the peak in incidence is known, projecting the magnitude of the incidence becomes the ultimate goal. To this end, we next conducted analyses of additional factors that could influence the seasonal pattern. Chief among these is the effect of climatic variability (both latitude and rainfall variability), but we also examined the effect of proximity to irrigation and to the zonal health center. Linear regression was used to model the variation in monthly disease consultation rates for children < 1 and 1-4 years of age. The models included the following independent variables: season (quarter of the year), latitude of the town in which the clinic serving the health area is located, proportion of the population not having access to irrigation, proportion of the population residing more than 15 kilometers from the health clinic (to control for ease of making consultations), and whether the year had a rainfall anomaly (excess years used for the diarrhea and malaria models, and deficit years for ARI).

Results

Rainfall records for the six health areas in Niono show significant climate variability in these zones. For the 1995-2004 period, there were negative rainfall anomalies (<-1 SD from 10 year average) in 1996 and 1997 and positive anomalies (>1SD from 10 year average) in 1999, 2001, and 2003. Both negative and positive anomalies varied in level and location. In 1996 all but one health zone had a negative anomaly, while in 1997 the exception for 1996 anomalies was the only zone with a negative anomaly. In 1999 and 2003 all health zones had positive anomalies, but in 2001 was a positive anomaly only for some of the zones. Figure 3 shows the variation in disease consultation rates by month and CSCOM for the two different climate zones.

Malaria is highest at the end of the rainy season, peaking in August-September with smaller peaks 2-3 months before and after the main incidence peak. The seasonality is more pronounced in the Sahelian zone. Fourier spectral analysis of monthly consultation for all Niono health zones is consistent with a dual harmonic pattern. The 12-month long harmonics is centered on September while a much smaller harmonic component, with a 6-month period, peaks in July-August and December-January (Figure 4) thus effectively "broadening" the main peak. Diarrhea peaks in the early rainy season, July-August, and the peak is sharper for the Sahelian zone time series. The Fourier spectral analysis shows 1 clear and 1 "blurred" harmonic period, with 6 and 12 month long periods (Figure 4). The overwhelmingly larger 12-month harmonic is centered on August. ARI incidence peaks twice yearly; first in March-May during the hot-dry season and later in August-October during the rainy season. The later is more pronounced in the savannah than in the Sahel. The Fourier spectral analysis of the ARI series is consistent with this biannual pattern; in this case, the 6 and the 12-month long periods are "in-phase." Although spectral analysis is based on all age groups, representing only a crude initial assessment of seasonal disease patterns, spectral similarities between the three diseases are remarkable. All three diseases show similar harmonic patterns, i.e. 6 and 12 month long periods, emphasizing the importance of seasonal rainfall variability. Rainfall Fourier anaslyses (not shown) display well-defined 6- and 12-month long harmonic components.

The models for malaria and diarrhea, for which higher rates were anticipated during periods of excess rainfall anomalies and also in zones with irrigation include the "excess rain" variable and the variable measuring degree of access to irrigation. ARI is not expected to be influenced by irrigation thus this variable is excluded from the model; furthermore, the variable describing excess rain is replaced by a deficit variable, to reflect the anticipated influence of drought on transmission of ARI. There was no significant effect of inclusion of the variable controlling for distance to the health center in the ARI model, so it was excluded from the final set of estimates. The estimated standardized beta, t-values, and significance are shown in Table 2.

The models estimating the variation in malaria incidence explain 49% of the variation in the rates for children under age 1 and 47% of the rates for children 1-4 years of age. For both age groups, the control for season is important in the explanation of variability. In addition, children living in the more northern latitudes (Nampala and Sokolo) have higher malaria rates than those in the southern section of the zone. Contrary to expectations, exceptionally rainy years do not impact malaria incidence after controlling for season, location, and other factors. The impact of irrigation is also contrary to expectations, with higher incidence in areas with a larger share of the population living in areas without access to irrigation. Finally, malaria incidence is decreased in health areas with a larger percent of the population living more than 15 kilometers from the clinic.

The model for the incidence of diarrhea is twice more powerful for infants than for children 1-4 years of age, explaining 28% of the variance in diarrhea incidence, compared to only 15% for children 1-4 years of age. After controlling for other variables, season does not have a significant effect on diarrhea incidence, but latitude is very important, with the more northern areas having a higher diarrhea rate. As with the malaria model, the influence of rainfall anomalies on diarrhea incidence is not significant, but access to the health center and to irrigation influences incidence, and in the same direction as for malaria incidence.

The model explains 12-14% of the variance in ARI incidence. The multivariate models demonstrate the need to control for seasonality to understand the variation in ARI incidence. Latitude also influences ARI incidence, but in the opposite pattern to that observed for malaria, namely with higher risk of ARI infection in the more southern areas. Finally, ARI transmission is significantly higher in both age groups during a dry year, when the rainfall is significantly below the average.

Discussion

These analyses have demonstrated the seasonality of the three childhood infectious diseases of interest: malaria, diarrhea, and acute respiratory infections. First, the spectral analyses demonstrate the periodicity of all three diseases, displaying two harmonic components. The greatest concentration of periodicity is exhibited for malaria. Diarrhea's harmonic components are broader and less marked than for the other two illnesses hinting at a greater contribution from non-seasonal elements. This is consistent with analysis of variance showing that, after controlling for the other factors expected to influence disease incidence, season of incidence has a significant effect on the incidence of malaria and ARI, but not diarrhea. The lack of marked seasonality for diarrhea in the multivariate analyses undoubtedly reflects the more spread out pattern observed for diarrhea with the spectral analyses.

Ecological zone, as measured by latitude, also significantly affects the patterns of disease incidence. Malaria and diarrhea are both more likely in the more northern zones, while ARI is more likely in the southern zones. As noted above, latitude is associated with the overall pattern of rains in the zone, with the more northern zones receiving rain later and for a shorter period of time, resulting not only in smaller average levels of rainfall, but also a season including more uneven distributions of rain. What is interesting to note is that it is the northern zones with less rainfall which are the ones with higher malaria and diarrhea rates, contrary to the expectation that these would be associated with greater rainfall.

It is possible that in the north the greater number of standing water sources, such as the seasonal lakes in Sokolo and Nampala, contributes to both greater mosquito reproduction and higher rates of water contamination. The northern villages have limited access to the formal irrigation canal structure, with the result that during the rainy season the seasonal lakes are carefully maintained by locally constructed dikes to provide villagers with a source of additional water for their animals and vegetable crops. Living near a dam has been shown to increase malaria and other waterborne disease transmission in Ethiopia.[33, 34] Second, the significance of the variable measuring the proportion of population without access to irrigation suggests that there could be other features related to arid agriculture that can contribute to malaria and diarrhea transmission. It has already been documented that mosquito population growth is higher in the irrigated areas of Niono, but that offsetting differences in the man-biting rates and other protective parameters reduce the malaria differential between persons living in the irrigated and unirrigated zones.[28] Another possibility is that the persons living in these northern zones are moving back and forth between their home villages and the irrigated zones, which have different transmission risks, as has been documented in Mali and other parts of Africa.[10, 35] Household surveys that were conducted among families in these health areas show that migrant families are less likely to use bednets, and particularly when they are moving about as seasonal workers. As a result, they are more likely to become infected, coming home with malaria.[36] Similarly, while migrating, families may not have access to clean water, which would also increase diarrhea transmission. The higher risk of ARI among children in the southern zone also needs to be examined in more detailed studies. Higher ARI incidence in the southern zones could reflect different housing and sleeping patterns, which could accelerate transmission, but certainly other factors are operating. Populations living in irrigated areas are more often exposed to gastro-intestinal pathogens and malaria leading to the development of low level immunity which is certainly not the case in the northern areas of the district.

We had expected that rainfall anomalies, both positive and negative, would be associated with higher levels of disease incidence, however the multivariate analyses showed that years in which there was excess rain were not associated with higher incidence of malaria or diarrhea. However, rain deficit years were associated with higher incidence of ARI. This is consistent with the findings that atmospheric dust increases during the dry years, contributing to higher transmission of respiratory illnesses.[37]

Contrary to expectations, children living in health areas with lower access to irrigation have higher risks of malaria and diarrhea. However, this is consistent with an earlier study which showed that while the transmission period is longer in the irrigated zone, the higher entomological inoculation and vector circum-sporozoite protein (CSP) infection sustain a higher malaria transmission rate in the non-irrigated than irrigated zones.[28, 29] The lack of access to irrigation could be a marker for poor access to the health care center; but the inclusion of the control for access to the health center (proportion of population living more than 15 kilometers from the health center) did not remove the effect of the irrigation variable. In addition to the possible effects noted above on migration and changed disease exposure, the lower access to irrigation could also serve as a proxy variable for levels of malnutrition, as the families living in the dry zone typically have significantly lower levels of food production and consumption. [38] Future studies will include specific measures of food production and consumption, as well as child malnutrition levels.

Conclusions and Implications

Spectral analysis demonstrates marked seasonal fluctuations for major childhood infectious disease in Niono, Mali, namely diarrhea, ARI, and malaria. These seasonal patterns vary with latitude, which is in turn associated with fluctuations in rainfall, related to the location of the ITCZ, and other components of climate variability. While our analyses only include the district of Niono, these findings have broad applicability to other Sahelian zones with similar seasonal patterns influenced by the ITCZ. Throughout the Sahel, recognition of these seasonal and contextual patterns of influence on disease incidence could open the way for more timely and effective health care interventions. The ultimate goal would be to further integrate the Fourier and linear regression models such that the latter is built upon the harmonic components unveiled by the former, thereby enabling a more precise modeling of the seasonal and contextual variations in childhood disease risk.

Given these seasonal and contextual influences, an effective strategy for intervening to reduce childhood illness and related mortality is to become "season-smart" in the implementation of child health programs. Rather than waiting for illnesses to arrive, as it predictably will, preventive programs should be implemented one or two months prior to the anticipated peak. This simple, thus easily implementable, linear regression model allows the public health response to be tailored; modeling of incidence variability, using the mentioned variables, enables the health sector to respond proportionally thus minimizing costs, morbidity, and mortality. This proactive implementation of preventive measures gives caregivers time to learn the danger signs of illnesses and to take preventive steps to reduce their children's risk of the disease. This would reduce the seasonal peaks and thereby contribute to a substantial reduction in serious childhood illnesses. For example, the WHO/UNICEF program for the Integrated Management of Childhood Illnesses includes sixteen preventive behaviors, of which several impact on the risk of malaria, diarrhea, and acute respiratory illnesses. Community and village health workers implementing IMCI could time their instructions and provision of supplies for the period before the months when the seasonal peaks are anticipated. The health centers could similarly gear up for the seasonal illnesses by ensuring that health care centers and village health workers have all the medications and supplies they need for treatment of these illnesses, to reduce the possibility of shortages and delayed responses.

If a "season-smart" approach were to be implemented, it could lead to major reductions in consultations and costs to families living in Niono and other zones with seasonal illness cycles. For illustrative purposes, if the seasonal peaks in malaria, diarrhea, and ARI pertaining to the CSCOMs in this study were removed, e.g. by a season-smart intervention, then costs would be significantly lowered**.** There are an estimated 3551 infants and 12,427 children 1-4 years of age in these health areas. Smoothing out the consultation rates to remove the peaks resulted in an annual reduction of 230-490 consultations for infants and 392-977 for children 1-4 years of age. Savings associated with averted consultations are attributed to: travel costs, fees paid to the health center, purchase of medications, and lost work. All costs were converted to dollars. The total annual cost savings for a family with an infant was $344-$750, while families with children 1-4 years of age would be expected to save $571-$1412. While these are only illustrative calculations, they show the potential gains to be had from tailoring our child health interventions to be season-smart.

Table 1: Description of the Niono Study Zones

	Health zone	Latitude	July-Sept Average rainfall (mm)	Villages	Households	Population	Children <5 years
Sahel	**Nampala**	15.3	264.9	25	1222	7485	1460
	Dogofry	14.8	302.3	21	3340	22696	4426
	Sokolo	14.7	298.9	16	2284	13776	2686
	Subtotal		288.7	62	6846	43957	8572
Savannah	**Boh**	14.1	388.3	9	1026	6671	1301
	Sirbala	14	343.7	24	3541	21356	4271
	Pogo	13.9	405.3	19	1118	11167	2178
	Subtotal		379.1	52	4659	22591	4405
Total				**114**	**12581**	**83151**	**16322**

Sources: Carte Sanitaire de Niono, DSSS-Niono, 2002; FEWS-estimated precipitation estimate

Table 2: Regression Coefficients of Factors influencing Variability of Disease Consultations

	0 – 11 months			**1 – 4 years**		
Malaria	**Beta**	**t**	**Signif**	**Beta**	**t**	**Signif**
Season	0.229	3.13	.002	0.289	3.86	.000
Latitude	1.301	7.98	.000	1.173	7.02	.000
ExcessRain	0.047	0.65	.515	0.056	0.77	.445
%Unirrig	0.704	4.70	.000	0.581	3.78	.000
%Pop >15km	-1.975	-8.29	.000	-1.782	-7.30	.000
R^2	.49			.47		
Diarrhea	**Beta**	**t**	**Signif**	**Beta**	**t**	**Signif**
Season	0.146	1.68	.096	-0.030	-0.31	.754
Latitude	1.002	5.17	.000	0.710	3.35	.001
ExcessRain	-0.018	-0.21	.835	0.034	0.36	.720
%Unirrig	0.571	3.20	.002	0.420	2.16	.033
%Pop >15km	-1.155	-5.49	.000	-1.140	-3.68	.000
R^2	.28			.15		
ARI	**Beta**	**t**	**Signif**	**Beta**	**t**	**Signif**
Season	0.222	2.34	.021	0.163	1.74	.085
Latitude	-0.214	-2.27	.025	-0.315	-3.39	.001
Deficit Rain	0.196	2.11	.037	0.197	2.15	.034
R^2	.12			.14		

Figure 1: Niono Study Sites

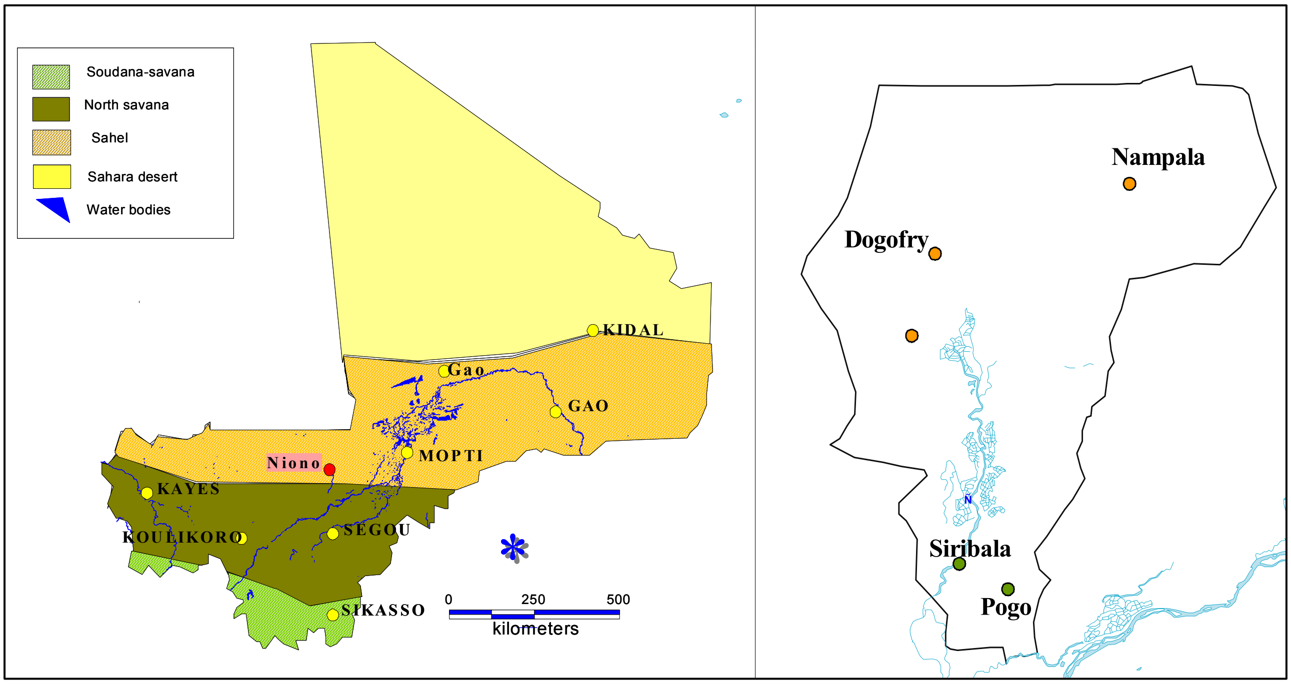


Figure 2: Rainfall Variations, Niono Health Zones (July-August-September, 1995-2004

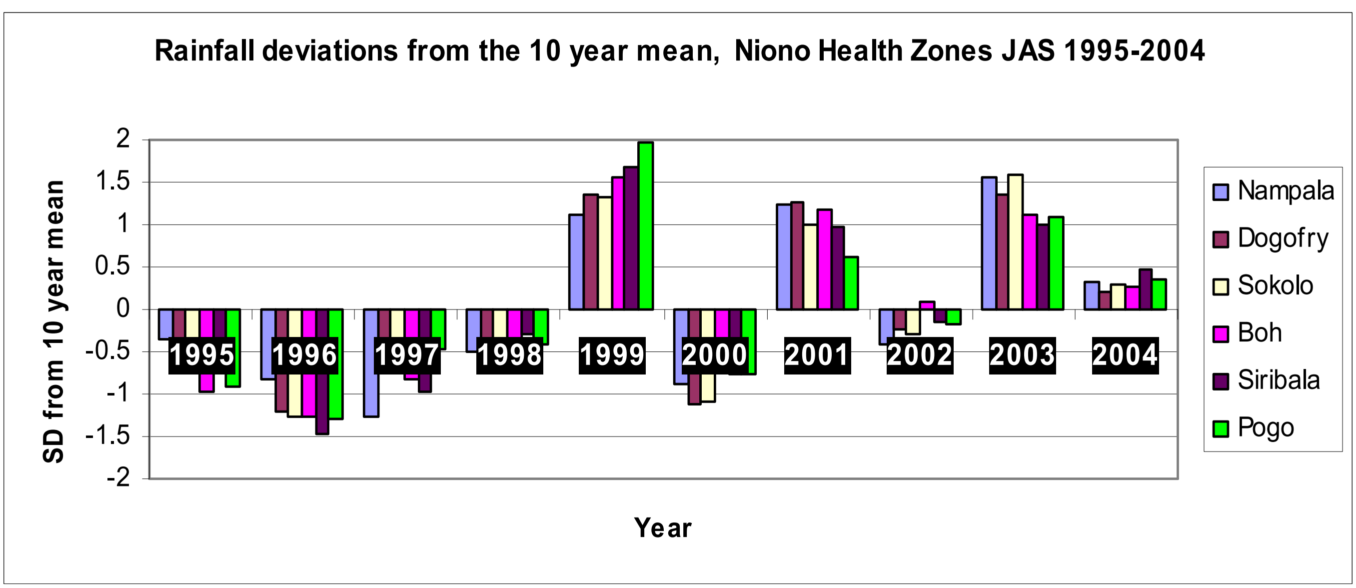


Figure 3: Monthly Disease Consultation Rates by Ecological Zone and Age, Niono, Mali

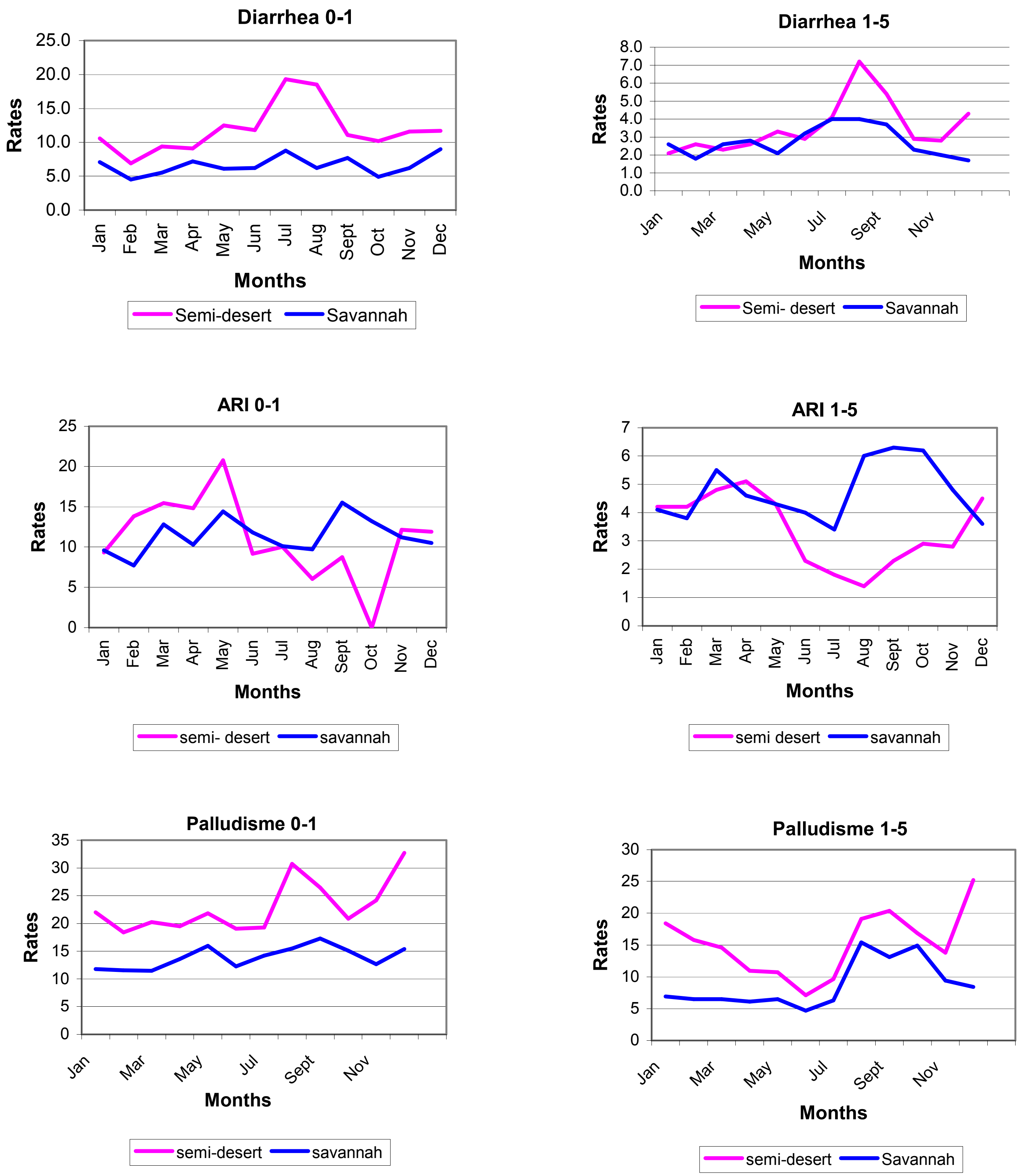
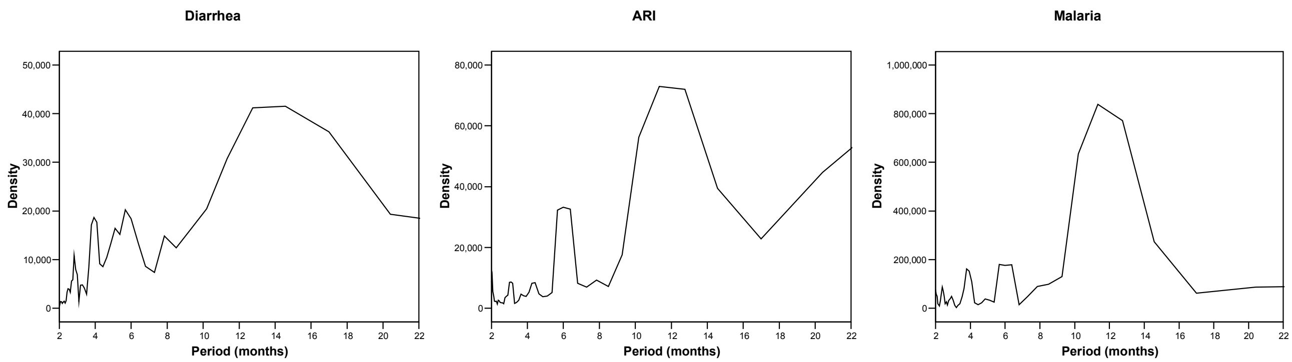


Figure 4: Spectral Analysis of Disease Time Series, 1996-2004



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