Climatic Variables and Transmission of Malaria: A 12-Year Data Analysis in Shuchen County, China

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SYNOPSIS

Objective. The objective of this study was to explore the impact of climate variability on the transmission of malaria, a vector-borne disease, in a county of China and provide suggestions to similar regions for disease prevention.

Methods. A time-series analysis was conducted using data on monthly climatic variables and monthly incidence of malaria in Shuchen County, China, for the period 1980–1991.

Results. Spearman's correlation analysis showed that monthly mean maximum and minimum temperatures, two measures of monthly mean relative humidity, and monthly amount of precipitation were positively correlated with the monthly incidence of malaria in the county. Regression analysis suggested that monthly mean minimum temperature and total monthly rainfall, with a one-month lagged effect, were significant climatic variables in the transmission of malaria in Shuchen County. Seaonality was also significant in the regression model and there was a declining secular trend in the incidence of malaria.

Conclusion. The results indicate that climatic variables should be considered as possible predictors for regions with similar geographic, climatic, and socioeconomic conditions to those of Shuchen County.

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Malaria is a life-threatening parasitic disease transmitted from person to person through the bite of a female *Anopheles* mosquito. Malaria is endemic to the poorest countries in the world, causing 300 million to 500 million clinical cases and more than one million deaths each year.[1] More than 90% of malaria deaths occur in Sub-Saharan Africa (approximately 3,000 deaths each day), and almost all the deaths are in children younger than five years.[1] Pregnant women are the main adult risk group in most endemic areas of the world.[1] Malaria is one of the major public health challenges eroding development in the poorest countries in the world. For instance, malaria costs the African nations more than US$12 billion annually.[1] Tropical Africa is estimated to account for more than 70% of all the malaria cases in the world.[2] Of the remaining cases, 75% are concentrated in nine countries: India, Brazil, Afghanistan, Sri Lanka, Thailand, Indonesia, Vietnam, Cambodia, and China. In these countries, malaria is often confined to specific regions and localities.[1]

Malaria is a serious public health problem in China. *Plasmodium vivax* can be found in many locations, and other types of *Plasmodium* can also be found in some epidemic zones. The main vectors are *Anopheles sinensis* and *Anopheles anthropophagu*.[3] Four malaria zones have been defined in China. The lowest malaria epidemic zone is located to the north of latitude 33° North. The higher malaria epidemic zone is to the south of latitude 25° North. The medium malaria epidemic zone is from latitude 25° North to latitude 33° North, and the malaria-free zone includes areas that are higher than 3,000 meters above sea level with annual average temperatures lower than 16°C.[3]

There are many potential risk factors for the transmission of malaria. Population immunity, mosquito control measures, social and economic status—as reflected in, for example, housing conditions and environmental factors including temperatures and rainfall—have been observed to have a significant impact on the transmission of the disease. In Rwanda, for instance, the incidence of malaria has been observed to be related to local climatic variables.[4] Few observations, however, have been conducted in relation to climate in China. It is important to study the impact of climate variability on the transmission of malaria in China because of its large population as well as continuing global warming.[5,6] These were the concerns that prompted an examination of the association between climatic variables and the incidence of malaria using a statistical model based on empirical data from Shuchen County, Anhui Province, for the period 1980–1991.

METHODS

Research site and population

With a population of approximately 0.7 million in 1991 and a temperate climate, Shuchen County in Anhui Province is located in the area between the Yangtze River and the Huai River, the largest and third largest rivers in China. As a national malaria surveillance location, the county has kept good records for malaria. It was therefore chosen as the site for a study of the relationship between climate variability and the transmission of malaria. All residents of the County during the period 1980–1991 were treated as the study population.

Data collection

Data on malaria cases were obtained from the Department of Diseases Surveillance, Anhui Anti-Epidemic Station. Population demographics for this county were provided by the Anhui Bureau of Statistics. Meteorological data were retrieved from the Anhui Bureau of Meteorology.

Data analysis

Data analysis was conducted with SPSS, Version 6.0.[7] The monthly incidence of malaria in Shuchen County was treated as a dependent variable, and climatic variables such as monthly mean maximum and minimum temperatures, monthly mean relative humidity, and monthly total amount of precipitation were independent variables. Spearman's correlation analysis was conducted to examine the relationship between monthly climatic variables and the incidence of malaria. Since there might be auto-correlations among both dependent and independent variables over time, Autoregressive Integrated Moving Average (ARIMA) and Generalized Least Square (GLS) regression analyses were performed to control for possible auto-correlations in the time-series data. A model was developed after the effect of auto-correlation had been removed by the ARIMA procedures, and GLS regression analysis was conducted to assess the independent effects of each climatic variable.[8]

The distributions of the monthly incidence of malaria and climatic variables were examined. Temperature and relative humidity were approximately normally distributed, while normal distributions of the monthly incidence of malaria and rainfall were obtained after logarithmic transformations.

RESULTS

Annual incidence of malaria in Shuchen County, 1980–1991

Figure 1 shows that the annual incidence of malaria in Shuchen County ranged from 14.3 per 100,000 population in 1990 to 1,008.4 per 100,000 in 1982. There was a remarkable reduction in the incidence of malaria after 1985.

Monthly variation in malaria incidence

Despite the apparent domination of the secular decline in incidence, Figure 2 indicates that there was monthly variation in the incidence of malaria in Shuchen County, with summer and autumn as peak times, although cases occurred in almost every month of the year. In years of high incidence, the summer peak was more pronounced compared to other years and there were substantial numbers of cases late in the year.

Correlation between climatic variables and monthly incidence of malaria

Spearman correlation analyses were conducted relating monthly incidence of malaria to various monthly climatic measures. Table 1 shows that monthly mean maximum and minimum temperatures, two measures of monthly mean relative humidity, and monthly amount of precipitation were positively correlated with monthly incidences of malaria in Shuchen County over the study period, with a one-month lagged effect. As an independent variable, the calendar month in which the cases occurred was correlated with the incidence of malaria, which indicated that there was a seasonal distribution in occurrence of the disease.

Cross-correlations among the independent variables were also conducted (Table 2). There were high correlations between monthly mean maximum and minimum temperatures. Because the correlation coefficient for the association between these two independent variables was larger than 0.6, these two variables were

Figure 1. Annual incidence of malaria in Shuchen County, China, 1980–1991

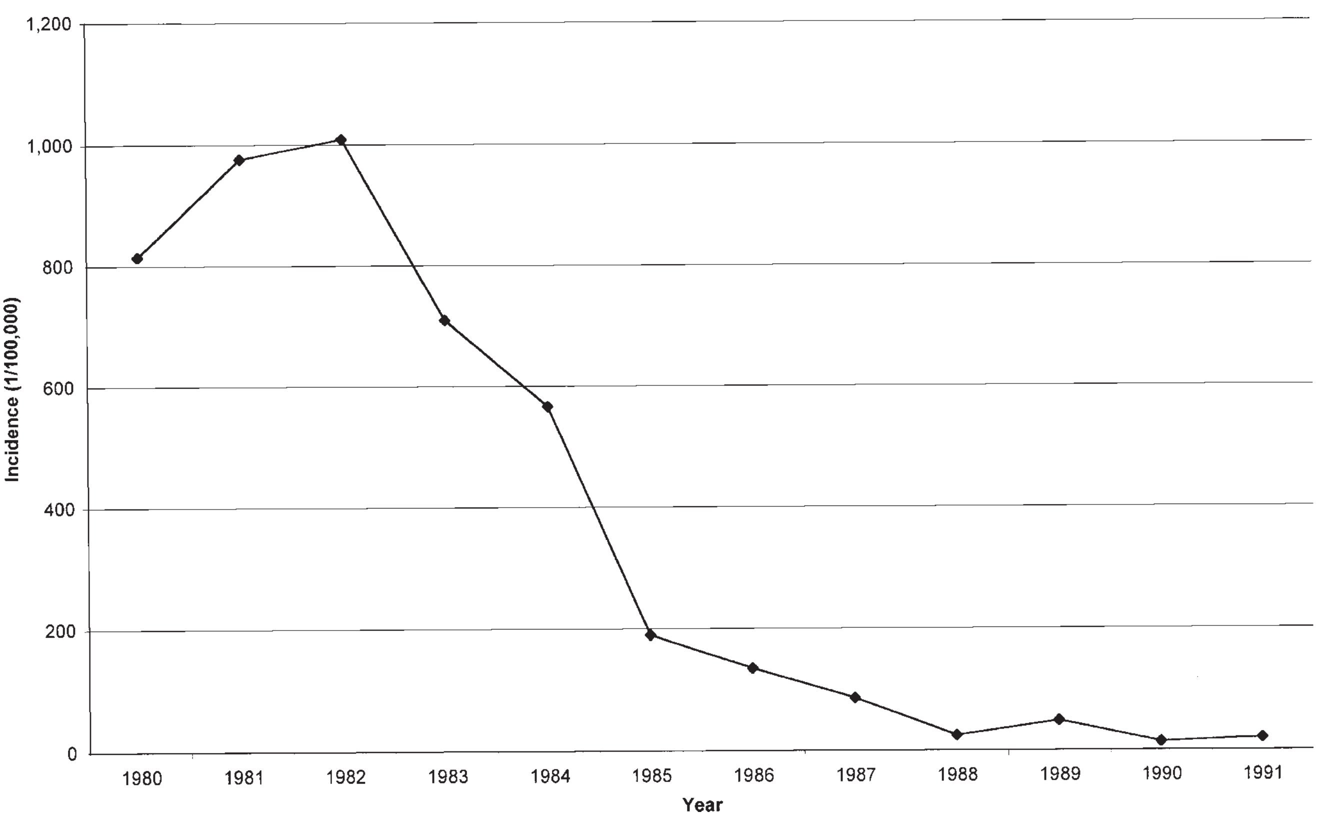

Figure 2. Monthly distribution of the incidence of malaria in Shuchen County, China, 1980–1991

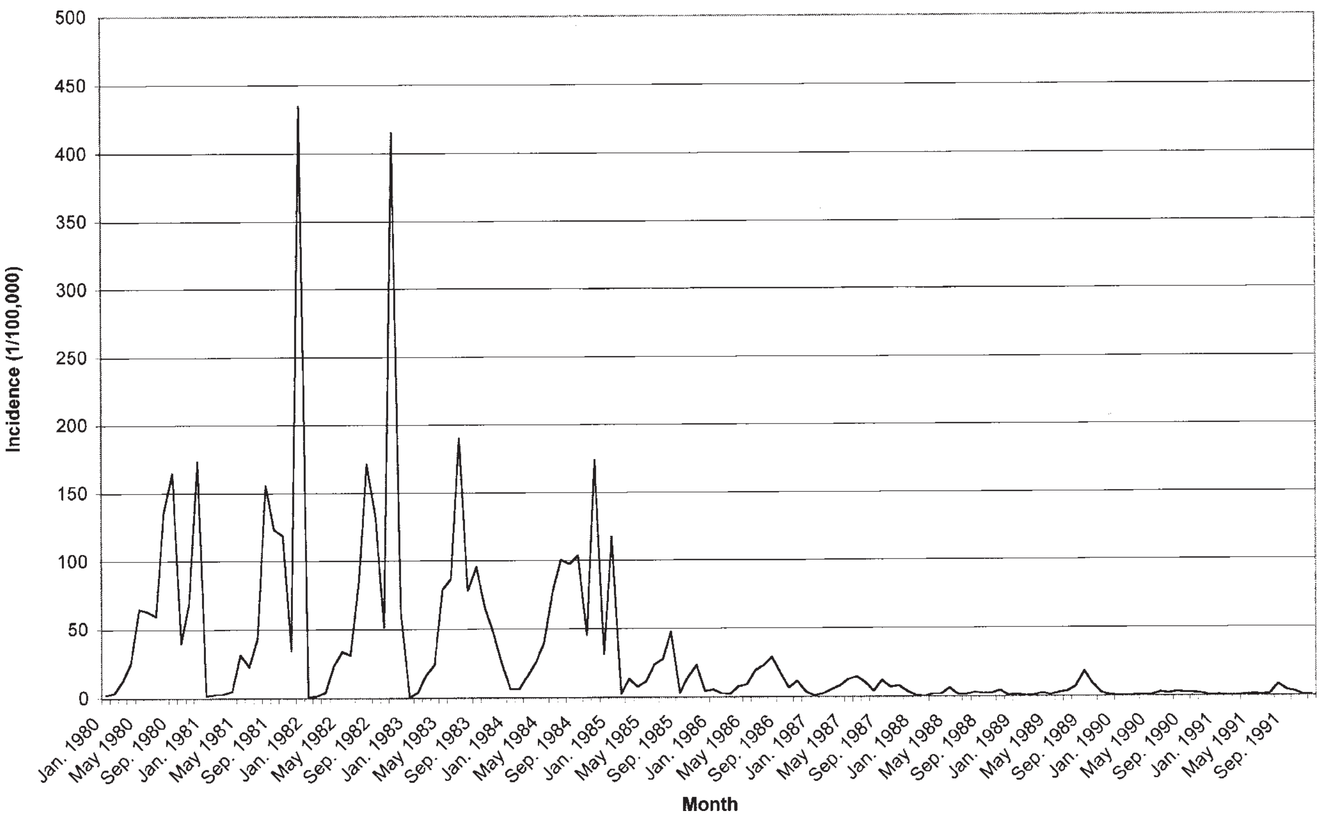

Table 1. Correlation between climatic variables and monthly incidence of malaria in Shuchen County, 1980–1991

	Monthly incidence of malaria	*p-value*
Season	0.382	<0.0001
MaxT P1	0.444	<0.0001
MinT P1	0.467	<0.0001
Rain P1	0.347	<0.0001
2 p.m. RH P1	0.313	<0.0001
8 a.m. RH P1	0.376	<0.0001

P1 = prior month

MaxT = monthly mean maximum temperature

MinT = monthly mean minimum temperature

Rain = total monthly rainfall

2 p.m. RH = monthly mean relative humidity at 2 p.m.

8 a.m. RH = monthly mean relative humidity at 8 a.m.

analyzed in separate regression models to reduce multicollinearity.

Climatic variables and monthly incidence of malaria

Monthly mean minimum temperature and total monthly rainfall, with a one-month lagged effect, were significant climatic variables in the transmission of malaria in Shuchen County (Table 3). This combination of variables yielded the best R^2, compared with other combinations of monthly mean maximum temperature and precipitation. When seasonality was included in the analysis, differences were found between autumn and both spring and winter (autumn was treated as the reference in the analysis), but there was no significant difference between summer and autumn. This supports our prior expectations of the seasonal distribution of cases (more cases in autumn and summer) and the impact of seasonality on transmission. Also "year" was a significant variable in the regression model, reflecting the secular decline in the number of cases.

Table 2. Correlation among climatic variables in Shuchen County, 1980–1991

	MaxT	*MinT*	*2 p.m. RH*	*8 a.m. RH*	*Rain*	*SOI*
MaxT	1.00					
MinT	0.98	1.00				
2 p.m. RH	0.35	0.49	1.00			
8 a.m. RH	−0.11	−0.09	0.50	1.00		
Rain	0.51	0.47	0.60	0.04	1.00	
SOI	0.07	0.07	−0.03	−0.08	0.05	1.00

MaxT = monthly mean maximum temperature

MinT = monthly mean minimum temperature

2 p.m. RH = monthly mean relative humidity at 2 p.m.

8 a.m. RH = monthly mean relative humidity at 8 a.m.

Rain = total monthly rainfall

SOI = Southern Oscillation Index

DISCUSSION

The transmission of malaria is determined by many factors, such as the vector-abundance of the *Anopheles* mosquito species, the propensity and frequency of the mosquitoes to bite human beings, its susceptibility to the parasite, the longevity of mosquitoes, the rate at which the parasite develops in mosquitoes, human behavior, population immunity, and the existence of the malaria parasite, as well as social factors such as housing conditions and mosquito control measures. Climate variability that impacts on the incubation rate of *Plasmodium* and the breeding activity of *Anopheles* is considered one of the important environmental contributors to malaria transmission.[9]

Table 3. Association of climatic variables with logarithmic transformation of monthly incidence of malaria in Shuchen County, 1980–1991

Variable	β	*SE* β	*p-value*
MinT P1	0.037	0.011	0.009
Lgrain P1*	0.241	0.106	0.025
Year	−0.173	0.016	<0.001
Spring	−0.278	0.136	0.041
Winter	−0.121	0.211	0.032
Summer	−0.195	0.193	0.313
Constant	1.954	0.211	<0.001

NOTE: $R^2 = 0.53$; DW = 2.02

SEβ = standard error of regression coefficient

MinT = monthly mean minimum temperature

Lgrain = log-transformed total monthly rainfall

Temperature rise is expected to increase transmission and prevalence of malaria by reducing the interval between mosquitoes' blood meals, thus decreasing the time to produce new generations, and by shortening the incubation period of the parasite in mosquitoes. Temperatures of 20°C to 30°C and humidity greater than 60% are optimal for *Anopheles* to survive long enough to acquire and transmit the parasite.[9] The extrinsic incubation period of the parasite shortens dramatically at temperatures in the range of 20°C to 27°C.[10] Temperatures lower than 16°C or higher than 30°C have a negative impact on the growth of the mosquitoes; also, at these temperatures the propagation rate of *Plasmodium* is reduced in the body of the mosquitoes. In endemic areas, therefore, malaria generally extends to the 16°C winter isotherm.[11]

This study in Shuchen County found positive correlations between monthly incidence of malaria and monthly mean maximum and minimum temperatures, with a one-month lag effect. The correlation coefficient for the association between monthly mean minimum temperature and monthly incidence of malaria was greater than that for the association between monthly mean maximum temperature and the incidence. This indicates that minimum temperature seems to play a more important role in the transmission of the disease than maximum temperature does. A rise of temperature, especially minimum temperature, would, in some locations, enhance the survival chances of *Plasmodium* and *Anopheles* during winter and thus accelerate the transmission dynamics of malaria and spread it into populations that are currently malaria-free and immunologically naïve.[4] A spatial shift may occur in both tropical and temperate regions if global climate change continues. The results of a similar study conducted in Rwanda suggest that monthly malaria incidence in high-altitude regions is related to changes in minimum temperature, while in low-altitude zones, rainfall and mean temperature are the most significant climatic factor.[4]

Rainfall plays an important role in malaria epidemiology because water not only provides the medium for the aquatic stages of the mosquito's life cycle but also increases the relative humidity and then the longevity of the adult mosquito.[9] In The Gambia, for example, malaria transmission is restricted largely to the rainy season.[12] However, the impact of rainfall on the transmission of malaria is very complicated, varying with the circumstances of particular geographic regions and depending on the local habits of mosquitoes. Rain may prove beneficial to mosquito breeding if moderate, but it may destroy breeding sites and flush out the mosquito larvae when it is excessive.[9]

This study indicates that total monthly rainfall was associated with the incidence of the disease in Shuchen County, with a one-month lag effect. The same results can also be found in observations of The Gambia[12] and in the intermediate rainfall zone of Sri Lanka.[13]

Both the correlation and regression analyses suggest that temperatures and rainfall act on malaria with a lag of one month. Because most of the malaria cases in Shuchen County were associated with *Plasmodium vivax*, such delays are consistent with the estimated minimum temperature generation time of a case of *Plasmodium vivax*—11–25 days (approximately eight days in the exoerythrocytic stage, two days in the erythrocytic stage, and nine days in the body of the mosquito).

"Seasonality" and "year" (time trend) played a role in the transmission of malaria in the County. Many factors may be responsible for secular and seasonal changes, e.g., climatic variables, ecological and environmental factors, host and vector characteristics, and social and economic determinants such as changes in health care infrastructure.

The range of vector-borne disease is not solely determined by climate variability.[14] Social, biological, and economic factors such as population immunity, housing conditions, mosquito control measures, local ecological environment (vegetation, introduction of irrigation schemes), and drug resistance also have a significant impact on the transmission of malaria.[9] Unfortunately, data on many of these conditions were unavailable in Shuchen County during the study period, although they might be very important in the transmission of malaria there. Figure 1 shows that the incidence of the disease declined over the period 1980–1991. The "reform and opening policy" in China starting in the early 1980s may have been an important contributor. This policy has improved the social and economic conditions in China and heralded a period of better health education and health promotion. These changes need to be addressed in further studies, although they have been treated as a secular independent variable (year) in this study.

Climatic variables that predict the presence or absence of malaria are likely to be best suited for forecasting the distribution of this disease at the edges of its range. However, the transmission of malaria is very complicated, and detailed ecologic and epidemiologic studies are still needed to assess the true local risk. Generally, these questions should be answered: How might local species of mosquitoes extend their breeding ranges in response to altered climate? What is their susceptibility to the malaria parasite? What species interactions—with competitors, predators, and parasites—might influence mosquito abundance? How might changes in abundance affect transmission rates? How do temperature, rainfall, and humidity affect the behavior and longevity of adult mosquitoes? What is the potential for malaria to be imported through human migration?[14]

Multidisciplinary cooperative research involving researchers from the fields of epidemiology, parasitology, botany, microbiology, and climatology is necessary.

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