Letter to the Editor

Application of Auto-regressive Linear Model in Understanding the Effect of Climate on Malaria Vectors Dynamics in the Three Gorges Reservoir[*]

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It is important to understand the dynamics of malaria vectors in implementing malaria control strategies. Six villages were selected from different sections in the Three Gorges Reservoir for exploring the relationship between the climatic factors and its malaria vector density from 1997 to 2007 using the auto-regressive linear model regression method. The result indicated that both temperature and precipitation were better modeled as quadratic rather than linearly related to the density of *Anopheles sinensis*.

China's Yangtze Three Gorges Project (TGP), one of the biggest hydropower-complex projects in the world, is located at North latitude 29°16'-31°50', East longitude 106°20'-110°30', including 25 county-level divisions of Chongqing Municipality and Hubei Province and with the total population of 16 million. The area had a history of falciparum and vivax malaria epidemic, with no indigenous falciparum malaria after 1960, and the transmission vectors were only *An. sinensis* with the density peaking from June to September in a recent surveillance[1], while the Three Gorges Reservoir has a humid subtropical monsoon climate, with a mean annual temperature of 15-19 °C, mean annual precipitation of 125 mm, and relative humidity of 76%.

Many studies have shown the annual precipitation and wet season temperature which defined the number and the geographical range of *Anopheles* mosquito in some areas. Mbogo and his colleagues in their preliminary climate analyses found the positive correlations between the precipitation and temporal distributions of *An. gambiae*. In China, some researchers have also reported that climate variables such as temperature or precipitation can indirectly affect malaria transmission. However, due to the lack of long-term data series on malaria vectors and the optimum analyzing method for these complex data, most recent studies assessing malaria risk in relation to climate changes has neither been qualitative nor modelling the cause-effect chain[2-3], and as a result the statistical relationships between the temperature or precipitation and malaria vectors have been significantly different among different areas.

Therefore, based on the previous related studies[1,4-5] and some experts' suggestions, we explored the relationship between the climatic factors and density of malaria vector in the Three Gorges Reservoir. Rather than predicting future conditions, our aim was to reveal the complex interaction between the temperature or precipitation and malaria vectors in the study area.

Based on the malaria incidence over the past three years, and the distribution of particular environmental features relating to the malaria transmission potential (e.g. paddy field or riparian zone), the study was carried out in six villages (Kaixian, Fengjie, Wanzhou, Fuling, Yubei, and Zigui). These villages are located at about the same altitudes (300 km) in different sections of the reservoir[1], and were used to collect the data of local malaria vectors. House design usually consisted of one- or two-room- mud-daubed construction with a low thatched roof. The eaves of most houses opened, which facilitated mosquito ingress and egress. The average family size was about five people per house, living together with their chickens, often dog, with a few big livestock. Cooking occurred typically inside the house or under the eaves of a porch. The detailed description of the study area and the maps showing the location of the selected villages are provided elsewhere[4].

Ten households were selected randomly upon

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receiving informed consent from the household heads from every selected village where the longitudinal survey was carried out in a population ranging from 500 to 1000 inhabitants. The longitudinal study was conducted from 1997 to 2007 in the same households. Indoor mosquito catches were performed every 15 d between May and August from 1997 to 2007 using motor mosquito catches (CN852021460) in the selected households. In each survey, mosquito's collections were carried out from 18:00 to 20:00. The collected mosquitoes were taken to the laboratory and killed by suffocation with chloroform vapor. They were counted and identified morphologically using taxonomic keys[1], and the density was calculated as the number of female adults per house per hour. The meteorological data from 1997 to 2007 were actual weather station records in the Three Gorges Reservoir, and the data of monthly precipitation as well as temperature for the period of the present survey were provided by the Chongqing and Yichang branches of the China Meteorological Agency.

Exploratory analysis indicated that the data were not normally distributed and lacked homoscedasticity. To maintain the assumptions for analysis, the average numbers in each catch (×) were log transformed to normalize prior to statistical analysis. A preliminary analysis was done on some climatic factors including the humidity, temperature, precipitation, wind, etc. Some climatic factors are highly correlated (with a Pearson correlation coefficient greater than 0.9), which, being revealed in the correlation matrix, indicates multicollinearity. Based on this statistical consideration and related studies[1,4-5], temperature and precipitation were chosen as potential covariates for the model. As in most ecological count datasets, the response variable (mosquito's counts as the mean density per month) exhibited in our study has a skewed distribution which may be due to over dispersion. If not properly modeled, the presence of variance heterogeneity may invalidate the distributional assumptions of the analyses, resulting in biased estimation of ecological effects and jeopardizing the integrity of the scientific inferences[6]. An alternative strategy for analyzing the count data, which avoids the problems inherent with the Poisson regression over dispersion/under dispersion, is to fit a negative binomial regression model[7]. The potential autocorrelation of the response variable was handled by adding a lagged dependent variable to the model. Therefore, the model is expressed as Log (mosquito counts)=method+district+time+temperature+temperature×temperature+precipitation+precipitation×precipitation. All the analyses of this study were carried out using the SAS9.1.

Consistent with the historical data[5], this study indicated that no other malaria vectors was caught except *An. sinensis*, and the density, expressed as the number of female adults per house per hour, was very small with the average density of only 2.7.

We analyzed the generalized auto-regressive linear regression of the density of *An. sinensis* against the average temperature and precipitation using all the data collected at the six study sites, including area and month as covariates. No statistical significance (Table 1) was observed among different areas (P>0.05). However, the most important finding was that *An.sinensis* density had a quadratic relationship with the average temperature and precipitation in corresponding month and both interactions were statistically significant (P=0.03, P=0.006), suggesting that nonlinear functions were more appropriate than linear functions for modeling the relationship between the average temperature and precipitation and the density of *An. sinensis* in our sample.

Above all, the study identified that the average temperature or precipitation varied with adult *An. density* in a highly nonlinear manner (Figure 1 and Figure 2). At lower temperature, the *An. density* increased with temperature which almost leveled off from 20.4 °C to 22.4 °C, and the most marked changes occurred at 22.4 °C where the density decreased rapidly in an accelerating manner from 22.4 °C to 28.4 °C, while the change slowed down toward higher temperature. Likewise, the density changed with precipitation in a manner similar to the relationship between the temperature and the density which increased with rising rainfall before 72.33 mm, while it decreased almost in a roughly linear manner from 72.33 mm to 500 mm.

Previous researches demonstrated that the monthly mean temperature or precipitation had a significant positive linear correlation with the density of mosquito in China using the correlation analysis method and stepwise regression method. However, our recent study identified that the breeding had the highest direct effect on vector and played a key role in mediating effect of temperature and humidity based on the structural equation mode[4]. Therefore, in this study we combined and integrated the present knowledge as well as the advanced statistical method to explore the relationship between the climatic factors and the density of *An. sinensis*, and the generalized auto-regression linear model regression analysis indicated that neither the temperature nor the precipitation had a linear relationship with the density of *An. sinensis* in the study area. Rather, their relationship was quite complex and similar.

However, the optimum temperature ranges for *An. sinensis* are from 20.4 °C to 22.4 °C in the study area, which are lower than those in Tanzania where the optimal temperature for endemic transmission is around 32-33 °C[8]. On the other hand, the optimal precipitation ranges for *An. sinensis* are about from 20 to 72.33 mm in the study area, which is also lower than those in Africa where the a minimum level of monthly precipitation of 80 mm is essential for seasonal malaria transmission[9-10].

Perhaps, the special topographic context, soil type, hydrological regime from the most remarkable environment changes in the Three Gorges Reservoir may partially explain the lower temperature or precipitation for *An. sinensis* in the study area. Since

Table 1. The Estimates Parameters of the Generalized Auto-regressive Linear Regression between the Density of *An. sinensis* and the Meteorological Variables

Parameter	Estimate	SE	95% Confidence		Chi-Square	Pr>ChiSq
Intercept	-27.92	13.79	-54.94	-0.89	s4.10	0.04
Area						
Zigui	-0.61	0.37	-1.33	0.11	2.76	0.10
Fengjie	-0.28	0.58	-1.42	0.86	0.24	0.63
Kaixian	-0.45	0.47	-1.38	0.48	1.50	0.36
Wanzhou	-0.14	0.41	-0.94	0.65	0.12	0.73
Yubei	-0.37	0.46	-1.27	0.53	1.16	0.45
Fuling	-0.40	0.42	-1.22	0.42	1.46	0.39
Month						
May	-0.21	0.59	-1.38	0.95	0.76	0.38
June	0.49	0.52	-0.52	1.50	0.39	0.53
July	0.14	0.56	-0.95	1.23	4.52	0.03
August	-0.04	0.58	-1.16	1.09	3.23	0.07
Climatic						
Temperature	18.62	10.50	-1.95	39.20	3.15	0.08
Temperature^2	-4.27	2.00	-8.19	-0.36	4.59	0.03
Precipitation	0.05	0.04	-0.04	0.13	1.17	0.28
Precipitation^2	-0.0035	0.0013	-0.0059	-0.0010	7.49	0.006
Dispersion	2.64	0.18	2.28	2.99	-	-

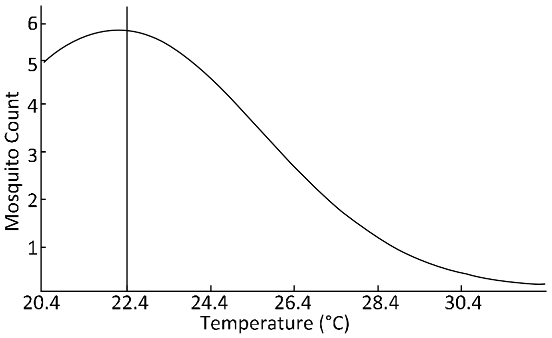

Figure 1. The relationship between the density of *An. sinensis* and the average temperature in the Three Gorges Reservoir from 1997 to 2007.

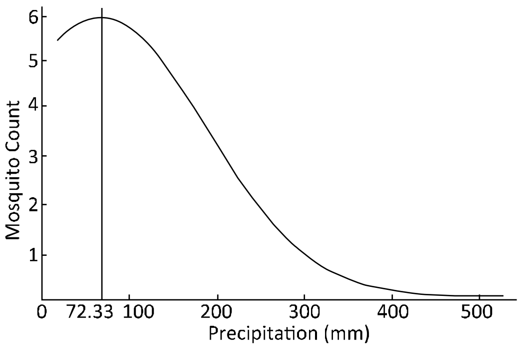

Figure 2. The relationship between the density of *An. sinensis* and the average precipitation in the Three Gorges Reservoir from 1997 to 2007.

the new hydrological regime brought about by the dam is the absolute opposite of the natural flood rhythms of the Yangtze River, natural peak flows occur during July, August and September (summer) with low flows in January, February, and March. The reversal of flooding times to winter, increased duration, as well as a regulated water level fluctuation zone with a 35 m magnitude, are going to dramatically alter the conditions in the riparian zone. As expected, we did find the statistically significant associations between the environmental variable and mosquito abundance, and the positive relationship of density of *An. sinensis* with the size of riparian zone[4]. Consequently, it would be of great interest to study the relationships between the water height in the reservoir and the Anopheles density.

Above all, the changes in local environment and in its demographic features are essential for understanding the complex system because they can create or reduce the number of suitable breeding sites for local vectors, thereby affecting their abundance through the climatic factors. Since the malaria transmission is highly unstable in the similar region, continuous climatic factors and entomological surveillance, as well as understanding how climatic factors affect malaria vector distribution, will provide a sound basis for achieving the malaria elimination program in the Three Gorges Reservoir.

However, some potential limitations of this model should be mentioned. First, the goal of this model is not to prove causal relationships, but rather to collect sufficient evidence for reaching a verdict of causation which can justify or direct management action. Second, some poor or unreliable surveillance data may give misleading results. Third, some socioeconomic factors such as the houses type, net-use should be completed for improving the model. Despite these limitations, this model provides a promising tool for exploring the potential impact of current and future interventions on malaria vector transmission in a systematic manner.

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