Original Article

Malaria Transmission Potential in the Three Gorges Reservoir of the Yangtze River, China*

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Abstract

Objective To define and evaluate the malaria transmission potential in the Yangtze River, following construction of the Three Gorges Reservoir.

Methods Six villages, namely, Kaixian, Fengjie, Wanzhou, Fuling, Yubei, and Zigui were selected for investigating the malaria transmission potential in the reservoir. Transmission potential was estimated by mathematical modeling and evaluation of the local malaria situation. Factors that influenced the transmission potential were analyzed using Poisson regression analysis in combination with Grey Systematic Theory (based on evaluation by the Delphi method).

Results Indirect fluorescent antibody data and the incidence of malaria in the local population were consistent with the malaria transmission potential calculated for the area. Multivariate Poisson regression analysis showed a statistically significant association between the riparian zone and the man-biting rate.

Conclusion The risk of a malaria epidemic can be forecasted using the malaria transmission potential parameters investigated here which was closely correlated with the riparian zone.

Key words: Malaria; Transmission potential; Yangtze River Three Gorges Reservoir; Riparian zone

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INTRODUCTION

The Chinese Yangtze River Three Gorges Project, one of the biggest hydropower projects in the world, is located 29 °16 '-31 ° 50 ' North latitude, and 106 ° 20'-110 ° 30' East longitude, in China. This region has 25 county-level divisions within the Chongqing Municipality and Hubei Province and a total population of 16 million people. The reservoir water level reached 172.3 meters above sea level in 2008[1]. As a consequence, substantial differences in the riparian zones of the different reservoir sections now exist. Although the reservoir infrastructure holds potential for alleviating poverty and promoting economic growth, adverse health effects may undermine these objectives[2]. Indeed, dams built in Cameroon[3], Kenya[4], and Mali[5] have increased the malaria burden, a trend that appears to hold true for small Ethiopian dams as well[6].

The Yangtze River has a history of *Plasmodium falciparum* and *P. vivax* malaria epidemics, but no indigenous falciparum malaria transmission occurred after 1960, and vector control stopped at the end of

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the 1980s. In the past, the vector that transmitted malaria was *An. sinensis*[7]. However, construction of a reservoir creates an enormous riparian zone that may provide favorable breeding conditions for a range of *Anopheles* mosquitoes[8-9]. Therefore, it is important to be able to define the malaria transmission potential in this reservoir system, so that plans can be made for adequate malaria control strategies in this area, if needed.

To define the malaria transmission potential in an area, the vectorial capacity index can be a better index than the entomological inoculation rate in areas with a low incidence of malaria[10]. MacDonald and others[11-14] identified the key entomological variables in malaria transmission as the biting intensity, survival rate, and anthropophily of the mosquito vectors. Based on these criteria, we selected six villages for surveying the vector biting intensity, and another four in which to investigate the human blood index (HBI), and the ratio of multiparous mosquitoes.

MATERIALS AND METHODS

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 in the reservoir (Figure 1), and were used for surveying the ecological characteristics of the local malaria vectors. The design of the houses usually consisted of a one- or two-room mud-daubed construction with a low, thatched roof. The eaves of most houses were open, which facilitated mosquito ingress and egress. The average size of a family was about five people per house, living together with their chickens and often a pig, but few other livestock. Cooking was typically done inside the houses or under the eaves of a porch. A detailed description of the study area and maps showing the location of the selected villages are provided elsewhere[15]. Malaria prevalence, antibody responses, and disease incidence surveys were conducted in the same villages at the same time.

Sampling Methods

To estimate the human biting rates, mosquitoes were collected in each village every 15 days using volunteer human-bait catches between May and October from 2008 to 2009. Following World Health Organization (WHO) recommendations, mosquito catches were performed by two adult volunteers from the local population working beside a bed net containing a sleeping person. Mosquitoes coming to bite the collectors or persons asleep, were detected using a flashlight, collected into glass tubes (CDC backpack aspirator: John W. Hock Co., Florida, USA) and placed in screened pint-sized containers. Collections were conducted for 30 min each hour from 18:00 pm to 06:00 am overnight, and the mosquito collectors worked 6-h shifts in pairs. One pair began the mosquito collections at 18:00 and the other pair at midnight. All mosquitoes that landed on people were assumed to have bitten and were collected and identified by their morphological features[16].

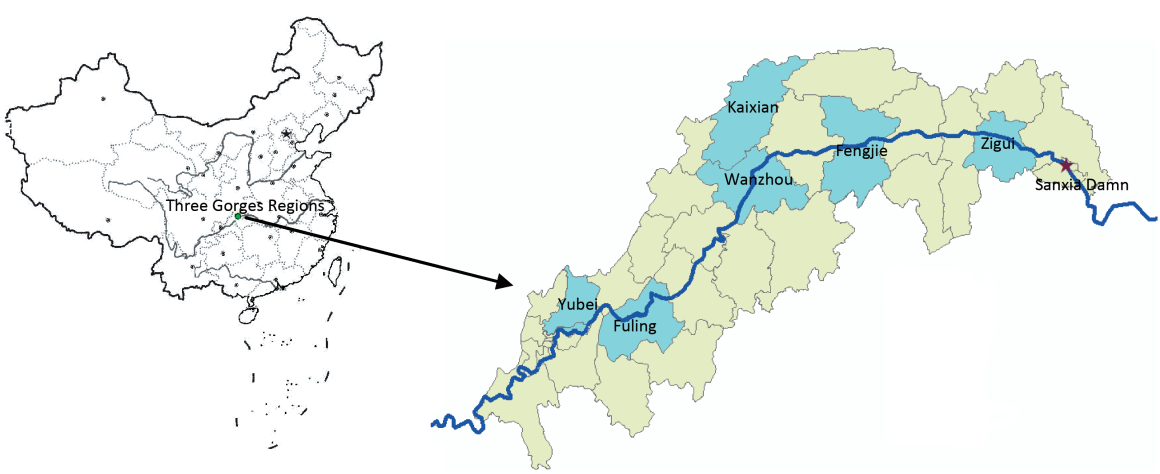

Figure 1. Location of study areas in Three Gorges Reservoir Area.

Estimation of Transmission Potential

Six villages were sampled simultaneously and the mosquito collectors were rotated among the six sites to eliminate bias. The mosquito biting rate was estimated by the number of mosquitoes caught per person per night in each village. The human blood index is often best estimated by applying the unweighted mean of a part-sample collected from different types of mosquito resting-place[17], and the average frequency of mosquito bites for a particular vector population is expected to be stable in given area, though mosquito feeding preference is strongly influenced by the availability of the specific hosts[18]. Therefore, we choose four villages to survey the human-blood index. Blood engorged *Anopheline* spp. were collected from different types of mosquito resting-place (i.e. the bush, empty cow-sheds, small warehouses, and concrete bunkers) using a CDC backpack aspirator (John W. Hock Co., Florida, USA), and blood meals were identified using the recipitin method[19]. Mosquito biting habits (a), were defined as the human blood index, divided by the length of the gonotrophic cycle, and estimation of the length of the gonotrophic cycle, as based on previous research data from China[20]. A survey to determine multiparous mosquito ratios was conducted in four villages where mosquitoes were dissected daily to determine their parity following WHO methodology[21-22]. Fifty percent of the female mosquitoes collected were dissected after each collection. The daily survival rate (P) was calculated according to Qian et al. (1994)[20]. We calculated *P. vivax*-infected *Anopheles* life expectancy values using the methods outlined in a similar study [n=105 /(T-14.5) (T for local average atmosphere temperature at that time)][20]. The vectorial capacity[23], which is defined as the expected number of new infections, per infective case, per day (provided all mosquitoes with sporozoites are potentially infective), was interpreted by Garret-Jones as the product of the man-biting rate (ma), the biting habits (a), and the longevity factor ($P^n/-\ln P$): $(VC)=ma^2(P^n/-\ln P)$. We calculated the basic reproduction number (R_0) using the formula: VC/r (where r is the average daily recovery rate of an infectious case); which serves as a threshold parameter that predicts whether an infection will spread. Hence, the critical man-biting rate ($CMR=-r1\text{og}nP/a$) below which there is no risk of an epidemic can be estimated. The stability index was calculated using the Gilles and Warrel[23] method. This vector-based index[24] differentiated stable malaria (values more than 2.5) from unstable malaria (values less than 0.5).

The Related Index for Assessing Malaria Transmission Potential

The Delphi method is a method based on expert opinion that was used here to identify factors associated with the risk of malaria transmission. A positive coefficient, authority coefficient and coefficient of concordance in the evaluation system comprising twelve related index (γ_1: the submerged land area per village; γ_2: the riparian zone per village; γ_3: the paddy area per village; γ_4: the rate of sleeping outdoors per village; γ_5: the ratio of pesticides use per village; γ_6: the ratio of screens and screen door use per village; γ_7: the average distance between house and animal stall per village; γ_8: the number of large livestock per village; γ_9: the number of pigs per village; γ_{10}: the ratio of bed-net use per village; γ_{11}: the average agricultural chemical use per village) for assessing the transmission potential built with the Delphi method through 3 rounds of consultation of 26 advanced experts from over the country was 0.92, 0.76, 0.39 (χ^2=38.84, n=24, P<0.01), respectively, indicating that forecasting or assessment by application of this evaluation system should be adequate for the purpose of this study.

Data Collection

On the basis of the evaluation system, the value of some of the economic indices (γ_4; γ_6 ; γ_7; γ_8; γ_9; γ_{10}) were households surveyed using standard questionnaires, with at least 100 houses in the six selected villages over 2 consecutive years participating. The value of the rest index (γ_1; γ_2; γ_3 γ_5; γ_6; γ_{11}) within 3 km from every village surveyed was collected from the Statistics Authority of the Local Government in Chongqing and Yichang.

Statistical Methods

A database was constructed and analyzed by SAS 9.1 (SAS Institute, Cary, NC). Comparisons were made using χ^2 tests. Grey correlation analysis was used to determine the main factors influencing the man-biting rate or human-blood index**.** With grey correlation analysis, the relationship between multiple factors can be analyzed objectively, with the important evaluation factors preserved for further analysis. The grey correlation coefficient was calculated by comparing the geometric correlation from historical data[25]. The association between the monthly man-biting rate (dependent variable) and the monthly selected index of higher weight (independent variable) was analyzed through application of Poisson regression analysis with the statistical significance level set at P=0.05.

RESULTS

Malaria Incidence

Fourteen malaria cases were confirmed in the local area between 2008 and 2009 (microscopy and travel history data). These were reported to the National Case Reporting System in Kaixian, Fuling and Wanzhou, but no cases were reported in Fengjie, Yubei and Zigui (Table 1), which indicated that the malaria incidence was low in this area. Furthermore, changes in the immunofluorescence assay (IFA) positive rate for the local population indicated the there had been an increase in the number of seropositive samples from the same population during the post-transmission period in Wanzhou, Fuling and Kaixian, than seen in the other study areas (Table 2).

Table 1. The Incidence of *Vivax* Malaria from National Case Reporting Information System from 2008 to 2009 in the Study Villages (1/100000, cases/persons)

Locality	Local Incidence	Imported Incidence	Total Incidence
Fengjie	0	0	0
Kaixian	0.24	0.12	0.36
Wanzhou	0.30	0.20	0.50
Fuling	0.18	0.18	0.36
Yubei	0	0.20	0.20
Zigui	0	0	0
Total	0.10	0.10	0.20

Table 2. The Change[15] of Serology (IFA) Result in Study Villages During the Transmission Period in 2008

Locality	May (pre-transmission)			October (post-transmission)			The Change of IFA of Local Population (%)
	No. sera	Positive		No. sera	Positive		
		N	%		N	%	
Fengjie	596	5	0.84	631	5	0.79	-0.05
Kaixian	600	4	0.67	605	10	1.65	0.98
Wanzhou	600	1	0.17	608	14	2.30	2.13
Fuling	618	5	0.81	624	15	2.40	1.59
Yubei	600	2	0.33	600	3	0.50	0.17
Zigui	599	9	1.50	732	6	0.80	-0.70
Total	3 613	26	0.72	3 800	50	1.45	0.73

Transmission Potential

Consistent with historical data[7], only *An. sinensis* malaria transmitting mosquitoes were caught in this study. The total average man-biting rate recorded for *An. sinensis* was 4.19, a value that peaked between May and June from 2008 to 2009. However, differences in the seasonal transmission dynamics, as well the following was observed during the study: Kaixian had the highest average *An. sinensis* density (peaking between May and August), whilst in Fuling and Wanzhou, the *An. sinensis* density peaked during May to July (Table 3). In contrast, few mosquitoes were captured in Zigui during the study period (Table 3).

The HBI in the study area was 0.10 and a statistically significant difference (P<0.05) among the HBI positive rates in the four localities was observed (Table 4).

No significant differences (P>0.05) existed among the ratio of multiparous of *An. sinensis* in the villages; the total ratio was 0.58 in this study, whilst the day survival rate at 0.85 was similar to a different study[20] (Table 5).

As indicated in Table 6, the man-biting rate and HBI were the major factors responsible for the discrepancy in the vectorial capacity in this survey. We found that the average vectorial capacity in the study area was 0.26, a value that peaked between May and June from 2008 to 2009. The estimated receptivity

Table 3. The Average Monthly Man-biting Rate from 2008 to 2009 in the Study Villages

Month	Time	Kaixian	Fuling	Wanzhou	Fengjie	Yubei	Zigui	Average
5	First ten days	8.75	2.00	1.50	4.00	0.50	0.00	2.79
	Last ten days	21.75	9.75	8.50	3.75	1.50	0.00	7.54
6	First ten days	22.00	12.00	12.50	5.00	3.50	0.00	9.17
	Last ten days	27.00	9.00	13.00	8.00	1.00	0.00	9.67
7	First ten days	6.00	14.85	10.00	5.50	2.50	0.25	6.52
	Last ten days	6.25	8.52	1.50	5.00	2.00	1.75	4.17
8	First ten days	8.00	7.50	1.50	4.75	2.00	1.50	4.21
	Last ten days	3.75	3.20	0.50	4.00	1.25	0.00	2.12
9	First ten days	2.00	3.38	0.50	3.75	1.75	0.00	1.90
	Last ten days	1.00	0.00	1.00	2.50	1.00	0.00	0.92
10	First ten days	0.50	2.50	0.00	2.50	0.50	0.00	1.00
	Last ten days	0.00	2.00	0.00	0.00	0.00	0.00	0.33
Total		8.92	6.23	4.21	4.06	1.46	0.29	4.19

Table 4. Blood-meal Identification of *An. sinensis* from 2008 to 2009 in the Study Villages

Locality	Number of Engorged Mosquitoes Collected	Total Tested Number	Percentage Containing Human Blood	Chi-square Test among Groups
Yubei	180	90	13.33	
Kaixian	208	104	20.19	
Wanzhou	543	181	8.29	P=0.000 χ^2 =22.56
Zigui	486	162	3.09	
Total	1 507	537	9.87	

Table 5. Parity of *An. sinensis* Collected in the Area during the Transmission Period

Locality	Test mosquitoes	Parous	Nulli-parous	Parity	Chi-square test Among Groups
Kaixian	166	85	81	0.51	
Zigui	122	69	53	0.57	
Wanzhou	204	135	69	0.66	P=0.062 χ^2=9.27
Yubei	65	34	29	0.52	
Total	557	323	232	0.58	

Table 6. Vectorial Capacity and Stability Index of *An. Sinensis* Estimated in the Study Villages

Locality	ma	HBI	A	P	N	1/-ln$p$	VC[1]	SI[2]
Kaixian	8.92	0.2019	0.08	0.82	9.08	5.04	0.64	0.40
Wanzhou	4.21	0.0829	0.03	0.89	9.45	8.58	0.39	0.26
Fuling	6.23	0.0829	0.03	0.86	9.89	6.63	0.31	0.20
Fengjie	4.06	0.0569	0.02	0.86	9.71	6.63	0.14	0.13
Yubei	1.46	0.1333	0.05	0.83	10.84	5.37	0.06	0.27
Zigui	0.29	0.0309	0.01	0.85	11.35	6.15	0.01	0.06
Total	4.20	0.0981	0.04	0.85	10.05	6.40	0.26	0.26

Note. [1]VC: Vectorial Capacity (ma×a×P^n/-ln$P$); [2]SI: index of stability (a/-ln$P$)

index (0.06 to 0.40) showed that malaria transmission was unstable in the area. In addition, the actual man-biting rate was 5.72, 3.37, and 2.87 times the critical human-biting rate in Kaixian, Wanzhou, and Fuling, respectively, while the other villages fell below their critical values (Table 7).

Table 7. The Comparison between the Actual Man-biting Rate and the Critical Man-biting Rate in the Study Villages

Locality	Kaixian	Wanzhou	Fuling	Fengjie	Yubei	Zigui	Total
r	0.1	0.1	0.1	0.1	0.1	0.1	0.1
-1ogn*P*	0.2	0.12	0.15	0.15	0.19	0.16	0.16
a	0.08	0.03	0.03	0.02	0.05	0.01	0.04
P^n	0.16	0.32	0.23	0.07	0.13	0.16	0.18
CMA[1]	1.56	1.25	2.17	10.71	2.92	10.00	2.22
AMA[2]	8.92	4.21	6.23	4.06	1.46	0.29	3.99
AMA/ CMA	5.72	3.37	2.87	0.38	0.50	0.03	1.61

Note. [1]CMA: the critical man-biting rate (-*r*1og*nP/aPn*). [2]AMA: the actual man-biting rate.

Overall, the local incidence of malaria, as well as the IFA results for the areas with greater vectorial capacities (Kaixian, Wanzhou and Fuling) were higher, and the of AMA/CMA index showed good agreement with the local malaria incidence (Table 8).

Table 8. The Comparison between the Transmission Potential and its Malaria Epidemic in the Study Area

Locality	Vectorial Capacity	AMA/ CMA[1]	Local Incidence (1/100000)	IFA[2]
Zigui	0.01	0.03	0	-0.7
Yubei	0.06	0.50	0	0.17
Fengjie	0.14	0.38	0	-0.05
Fuling	0.31	2.87	0.18	1.59
Wanzhou	0.39	3.37	0.30	2.13
Kaixian	0.64	5.72	0.24	0.98
Total	0.26	1.61	0.10	0.69

Note. [1]AMA/ CMA: the ratio of the actual man-biting rate and the critical man-biting rate. [2]The change of serology (IFA) result in study villages during the transmission period in 2008.

Relationship between Transmission Potential and Its Evaluation Indexes

The grey relational grade between the man-biting rate and evaluation indexes was ranked in the following order: $\gamma_1 > \gamma_2 > \gamma_3 > \gamma_5 > \gamma_8 > \gamma_4 > \gamma_6 > \gamma_7 > \gamma_9 > \gamma_{10} > \gamma_{11}$. Five indexes with bigger weights were selected for multivariable Poisson regression analysis which showed that the association between the riparian zone and the man-biting rate was statistically significant (χ^2=5.00, *P*=0.03) (Table 9).

Table 9. The Association between Man-biting Rate and Selected Indexes with Multivariable Poisson Regression Analysis

Variable	RR	95% CI		χ^2	*P*
γ_1	0.99	0.96	1.03	0.08	0.77
γ_2	1.07	1.01	1.14	5.00	0.03
γ_3	1.18	0.20	7.10	0.03	0.86
γ_5	0.01	0.00	2.10	2.80	0.09
γ_8	1.01	0.53	1.93	0.00	0.98

Note. γ1: the submerged land area per village, γ2 : the riparian zone per village, γ3 : the paddy area per village; γ5 : the ratio of pesticides use per village, γ8 : the number of big livestock per village.

DISCUSSION

The transmission potential of an area can be used to predict malaria epidemics. In fact, the vectorial capacity of a mosquito species is not an absolute value, but an index used to compare the potential or actual vectorial importance within a given area, and is, therefore, a powerful tool for simulating malaria transmission dynamics, especially in those areas where sporozoite rates are very low[26]. For example, an overall reduction in the vectorial capacities of three *Anopheline* species in Venezuela could be explained by the marked reduction in their prevalence[10], whilst the critical vectorial capacity was able to be specified from epidemiological data collected in a WHO study in Northern Nigeria[27].

Qian et al. (1994)[20], also conducted an in-depth study into vectorial capacity, using quantitative analysis of a large field-data set. This particular study was able to explain the marked reduction in the malaria incidence rate during 1982-1984, as well as the critical value for the man biting rate and the vectorial capacity in the surveillance areas comprising seven Chinese provinces and municipalities during 1992-1994[20]. In the present study, it was not surprising to find that in the area where no malaria was found (Zigui, Yubei and Fengjie), the estimated man biting rate and vectorial capacity were below those in areas where malaria was present (i.e., Kaixian, Wanzhou and Fuling). Moreover, the *P.vivax* antibody levels in the populations were consistent with the vectorial capacity: those in Kaixian, Wanzhou and Fuling had greater vectorial capacities than the other areas (Zigui, Yubei and Fengjie). Interrupted human-vector contact, decreased anopheline population sizes, and effective malaria treatment may all have contributed to the lack of malaria in these areas (Zigui, Yubei, and Fengjie). The basic reproductive number, R_0, should also be taken into account here as it plays a central role in epidemiological theory for malaria transmission[28] where it can provide an index of transmission intensity and establish a threshold criteria. Therefore, the Critical Man-biting Rate[29], meaning the minimum level of *Anopheles* density or man-biting rate that is required to maintain transmission, can be inferred from the basic reproductive rate. Consequently, the level of vector control required in a malaria epidemic can be quantitatively estimated by comparing the actual man-biting rate and the critical man-biting rate. Indeed, the critical man-biting rate index has already proved useful for the assessment of malaria transmission or interruption in a series of studies in China[30-32]. Our findings are consistent with this assessment, where it was found that the actual man biting rate was higher than the critical man biting rate for indigenous malaria cases in Kaixian, Wanzhou and Fuling, whilst the actual man biting rates were below the critical value in Zigui, Yubei and Fengjie villages that did not have any malaria cases. Above all, the results of this study make it clear that the malaria transmission potential was in good agreement with the epidemic status of the Three Gorges Reservoir area.

The man-biting rate and human-blood index were the major factors responsible for the variation in the vectorial capacity, which in turn was related to variations in the ecological environment of the area. Vector species abundance, longevity, feeding cycle length, and vector blood meal choice are key predictors for the transmission intensity of insect-borne diseases such as malaria[33-34]. The proportion of feeds taken on humans is influenced by host preference and availability[35], so changes in host abundance may influence malaria transmission. In addition, spatial variation in mosquito biting habits and resting behaviors have been observed[32]; within almost all *Anopheles* species, such heterogeneities may result in differences in the man-biting rate within different areas. In common with previous studies[36-39], we found significant discrepancies in the ecological habitats of the malaria vectors in the area, as well as a statistically significant difference (P<0.05) among the human-blood index in the four localities. We also found substantial spatial-temporal variations in mosquito abundance. *An. sinensis* adults were more abundant between May and June and those in Kaixian and Fuling had higher numbers than those in Yubei and Zigui. In an elegant series of studies[12-14], it was shown that for a particular species, two or more factors are important in determining the vectorial capacity of a mosquito species to transmit malaria within a certain area. The result of these studies also indicated that the man-biting rate and human-blood index were the major factors responsible for the big discrepancy in vectorial capacity in the area. Furthermore, the findings from this study also indicated that the human-blood index and man-biting rate were closely related to ecological environments that included, for example, human behavior (sleeping outdoors) and socio-economic (mosquito net use) factors, as well as environmental factors (riparian zones), using the grey relational grade analysis in combination with Poisson regression analysis based on the evaluation system of the Delphi Method[12-14]. Hence, variation in vectorial capacity was attributed to heterogeneity in ecological and environmental factors in the study area[12-14].

In the present study, the riparian zone influenced the stability of the transmission potential by increasing the density of *An. sinensis* in the area. MacDonald's stability index represents the mean number of bites per human taken by a vector during its entire lifetime, the higher this index, the lower the *Anopheline* density necessary to continue transmission. The estimated stability index range was 0.06 to 0.40 in the Three Gorges area. Thus, malaria transmission is highly unstable in this area. Similar findings have been reported in elevated areas within Zimbabwe[40], the high plateau of Madagascar[41], and Pajushi in Korea[42]. The new hydrological environment of the Three Gorges Reservoir dam is completely different from the natural flood rhythms that would have occurred in the past in the Yangtze River. Natural peak flows occurred during July, August and September (summer) with low flows in January, February and March (winter)[43]. The reversal of the normal flooding times to winter, increased duration, as well as a regulated water level fluctuation zone of some 35m magnitude, is going to dramatically alter the conditions in the riparian zones[44]. These flow characteristics interact with other environmental factors to form a wide range of variables that can influence the riparian zone. Logic would suggest that drawdown in the growth season (summer) would be conducive to breeding habitat formation for malaria vectors, compared to the previous hydrological environment. As expected, we found a statistically significant (Table 9) association between this environmental variable and mosquito abundance (using multiple Poisson regression analysis as well as the grey relational grade analysis), and the density of *An. sinensis* was positively related to the size of the riparian zone. In addition, the field survey showed that when the drawdown area was exposed to land during hot and humidity days (from April to October), a lot of small water pits became distributed in the riparian zone. This may have been caused by a period of about 6 months where the soil was soaked with water making drainage difficult. In the riparian zone, we noted the presence of garbage, weeds, and other pollutants detained in the fluctuating band, thus it appeared likely that a large number of mosquito breeding sites could form during the malaria transmission season. Because malaria transmission in the area was highly unstable with low incidence, transmission could vary according to local changes, but the riparian zone was the highest risk factor impacting the transmission potential by increasing the density of *An. sinensis* in this area. Therefore, the riparian zone influenced the stability of malaria transmission by increasing the density of *An. sinensis* in the reservoir area.

Though the vectorial capacity and the basic reproduction number of infection have long underpinned both concept and methodology for quantitative studies of malaria transmission, the measurement of anopheline vectorial capacity has substantial technical and analytical problems. Such problems raise important questions about precision (random error) and bias (systematic error), because credible direct estimates of vectorial capacity require robust data, whereas the most tractable epidemiological problems will pose comparative rather than absolute questions.

With relatively high transmission potential existing in some regions of the Three Gorges Reservoir (Kaixian, Wanzhou, and Fuling) and the riparian zone influencing malaria stability in the area, we should pay attention to the impact from ecological environmental change on the potential transmission of malaria and its stability. Hence, early warning of malaria transmission is important for reducing the risk that this disease poses to public health. It is hoped that this study will assist understanding of the influence that dams have on malaria transmission. It is also hoped that mitigation strategies to alleviate potential negative health effects can reduce the disease burden in areas where malaria is unstable. However, additional studies are needed to learn how the dam system influences malaria transmission to enable sufficient information to be gathered to assist any future malaria eradication programs.

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