FACTORS INFLUENCING MALARIA ENDEMICITY IN YUNNAN PROVINCE, PR CHINA (ANALYSIS OF SPATIAL PATTERN BY GIS)

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Abstract. This study is an initial attempt to apply disease mapping through Geographical Information System (GIS) with multiple regression analysis to determine the nature and extent of factors influencing malaria transmission in Yunnan Province, PR China, particularly in border areas. Secondary county-based data covering the period 1990 to 1996 were collected and analyzed. The malaria situation in Yunnan Province as a whole is influenced mainly by the combined effects of the physical environment, the presence of efficient vector species, and mobile population along international borders with Myanmar, Lao PDR and Vietnam.

INTRODUCTION

Yunnan Province is situated in the southwestern frontier of PR China. It has borders with Myanmar, Lao PDR and Vietnam with a 4,060 km boundary line. Within the province, the elevation ranges from 76.4 m to 6,740 m with diverse topography and striking variations in weather. Under the jurisdiction of the province, there are 128 counties, 26 of which are located on the international borders.

Historically, Yunnan has been hyperendemic for malaria. Due to more than four decades of anti-malaria efforts, malaria incidence has decreased significantly. However, the number of cases and deaths, and annual incidence rates of malaria in Yunnan have been the highest in the entire country in the past 3 years. The proportion of malaria cases in Yunnan to the total in China increased from 4.3% in 1986 to 31.94% in 1996 (YPIMC, 1991, 1996). Moreover Yunnan is one of two provinces still having transmission of indigenous *Plasmodium falciparum (Pf)*. Malaria has been the second or third leading cause of morbidity among communicable diseases in the province in recent years (Zhu *et al*, 1996). Thus, Yunnan is a top priority concern of malaria control in China.

There is an Epidemic Information System for monthly reporting of the 35 notifiable communicable diseases from peripheral to central level throughout China. However, with regard to malaria, only the number of cases, number of deaths, incidence rates and case-mortality rates are included in the system. Standard "Reporting Forms of Annual Malaria Control Activity" were used for documentation and reporting of detailed data by 1990 in Yunnan. These data are contained separately in more than 10 tabular forms. Factors relating to malaria transmission such as climatic and socio-economic data have not been integrated into the malaria database.

The Global Strategy for Malaria Control requires strengthening of the information systems, particularly in all areas prone to epidemics. Information systems constitute a vital element for assessing the malaria situation and for selecting appropriate control measures at any given time. Since different types of data and information have spatial properties, an information system that incorporates geographic aspects can be useful. Geographical Information Systems (GIS) provide a comprehensive computer database technology that allows all types of geographic information to be integrated, interrelated, and handled in a unified way. Spatial patterns can be perceived and correlation visualized through the use of maps. Thus maps can be drawn of "typical" spatial and temporal relationships among environmental factors, socio-economic activities and disease incidence.

This study used disease mapping through GIS with multiple regression analysis to determine the nature and extent of factors influencing malaria transmission in Yunnan Province, particularly in border areas.

MATERIALS AND METHODS

Yunnan Province of China was selected as the study area using county as the geographical unit of observation. Relevant data covering the period of 1990 to 1996 (some from 1986 to 1996 and some from 1994 to 1996) were collected and analyzed from February to May 1998.

Data collection

This study used secondary data extracted from reports, documents, databases, and books developed or issued by several authorities. Data on the following were recorded from reporting forms of annual malaria control activity 1990 - 1996: number of species.

Total population, proportion of agricultural population, average annual income of farmers, hospital beds per 1,000 population were recorded from annual Statistic Year Book (1991-1997) issued by the Provincial Statistic Bureau. The number of bordercrossing movements during 1990-1996 were provided by the Provincial armed Police for Frontier Guard. This number represented the person-times of foreigners entering into Yunnan and of Chinese going out of Yunnan through the national and provincial official border-cheeking ports located in some counties along the borders with Myanmar, Lao PDR and Vietnam. The actual number of border crossing is probably larger due to unreported population movements.

Annual rainfall and annual mean temperature were obtained from the database of the Provincial Meteorology Center. Average values of several years' annual rainfall and annual mean temperatures were also obtained from the Statistic Year Book (1991-1997). Forest coverage of each county was obtained from the Provincial Forest Bureau. These values were the result of sampling surveys conducted in the last ten years (1985-1994). There is only one value for each county and these values do not reflect forest coverage in the same year. Data on elevation were obtained from the series of books of Introduction of Prefecture and Counties issued by the Provincial Compilation Committee for Provincial Annals. The series has 17 books, each for one prefecture.

Analysis

Data collected were entered by using Excel Software whereby data of each county were assigned an ID code as in the digitized map. A time code was added to distinguish the data of different years. The digitized map of Yunnan Province with county boundary was obtained from HEEDNet in CD disc (provided by HEEDNet). Each county has a specific ID code which serves as the link between attributable data and corresponding spatial area. MAPINFO Professional® version 4.0 was used to create maps. Binary and multiple variables with diverse combinations were displayed simultaneously on one single map, showing either interrelationship or trend.

Multiple regression analysis using the program of STATISTICA for windows® 5.0 (Statsoft Inc 1995) was done to assess the magnitude of effect of factors on malaria incidence rate (AMIR). Annual mean temperature (TEMP), annual rainfall (RAIN), lowest elevation (ELEV), forest coverage (FORE), location (LOCA) (along international border or not), annual average income per capita of farmer (ICOM), proportion of rural population (RURA) and number of hospital beds per 1,000 population (HBED) were selected as proxies of some potential determinants of possible variations in malaria incidence rates. Values of annual malaria incidence rates were transformed into natural logarithm values to satisfy the assumption of linear regression analysis.

$$\text{Log AMIR} = b_0 + b_1\,\text{TEMP} + b_2\,\text{RAIN} + b_3\,\text{ELEV} + b_4\,\text{LOCA} + b_5\,\text{FORE} + b_6\,\text{ICOM} + b_7\,\text{RURA} + b_8\,\text{HBED}$$

RESULTS

Maps

Distribution of malaria:

Malaria has occurred persistently in counties along the borders with Myanmar, Lao PDR and Vietnam and along the Yuan River (Fig 1). In fact both malaria incidence rate and number of cases are much higher here than in other areas. Since data in some years are incomplete, the unusually high incidence rates in Wanding and Hekou counties can not be explained.

As of 1995, while *Plasmodium vivax* (*Pv*) is the dominant species in the entire province, *Pf* occurred mainly in border counties with a proportion of up to 50% of total cases. The total number of malaria cases reported in 1995 in Yangbi (1 case), Huaning (1 case) and Luxi (2 cases) counties were small so that when expressed in percentage, give values of 50% -100% which happened to be falciparum cases (Fig 2). The pattern remained similar in the past 5 years. The seasonal pattern of malaria is evident in high incidence areas. As it is, transmission begins in May or June and peaks in July and August. The same trend has been seen in the last 6 years. This observation coincides with the hot, wet period. Malaria morbidity fluctuated from year to year during 1986-1996. The patterns varied among counties.

Factors influencing malaria incidence rate:

Malaria incidence rates are higher in areas with temperatures above 18° C (Fig 3), rainfall of more than 1,000 mm, denser forest coverage, and lower elevation. However, in certain instances, flushing of larval habitats might have occurred temporarily reducing mosquito densities. Incidence rates are higher in border counties and counties along Yuan River. To date, *Anopheles minimus, An. sinensis, An. kunmingensis, An. anthropophagus* and *An. jeyporiensis* have been identified as major malaria vectors in Yunnan. From data collected, malaria in border counties and counties along Yuan River is associated mainly with *An. minimus* (Fig 4) and possibly *An. kunmingensis* and *An. jeyporiensis* especially in the mid-western border counties with Myanmar.

Multiple regression analysis:

There is no multicolinearity among selected independent variables, therefore, these independent variables are statistically independent of each other. Results of regression are showing in Table 1. Fifty-two percent (52%) of variation of malaria incidence rate can be explained by 5 independent variables. The relatively moderate of R square value indicates that some other variables are not accounted for in this model.

With other independent variables being constant, every one degree increase in temperature corresponds to 1.2/10,000 higher malaria incidence. In like manner, when rainfall increases by 100 millimeters, malaria will increase to 100.0/10,000 and for every 10% increase in forest coverage, 14.5/10,000 higher incidence rate. A border county will have an increase in malaria of 6.5/10,000, more than a county which is not located along the border. Elevation has a negative correlation with malaria in which every 100 meters decrease in elevation will result in 99.8/10,000 increase in incidence rate.

Other variables such as income of farmer, the proportion of agricultural population and the number of hospital bed per 1,000 population had no significant association with malaria incidence rate.

DISCUSSION

The results of disease-mapping using GIS are generally consistent with the results of statistical regression analysis. Both methods show that malaria incidence in Yunnan is significantly affected by the physical environment.

Temperature directly influences mosquito development, gonotrophic cycle and longevity, as well as the duration of the extrinsic cycle of plasmodial parasites in mosquitos and, indirectly affects vegetation and breeding sites. High relative humidity prolongs the life of the mosquito enabling it to transmit the infection to several persons. Rainfall favors high humidity, thereby, enhancing vectorial potential (Gilles and Warrell, 1993). Higher temperature and heavier rainfall increased malaria incidence in Yunnan. These observations are consistent with other studies elsewhere. Loevinsohn in 1994 reported climatic warming and increased malaria incidence in Rwanda. Bouma's study of malaria and climatic change in the North-west Frontier Province of Pakistan in 1996 showed a coincidence between increase in temperature, humidity and increase in *P. falciparum* infection. Correlation of rainfall with upsurge of malaria in Rajasthan showed that prolonged rains are associated with significantly higher incidence of all cases and of falcipaum malaria in particular (Gupta, 1996). Conversely, drought in the Niayes area of Senegal, caused by the drop of annual rainfall over a 30-year interval was associated with decreasing parasite index in children (Faye *et al*, 1995).

In Yunnan, the temperature of areas with the

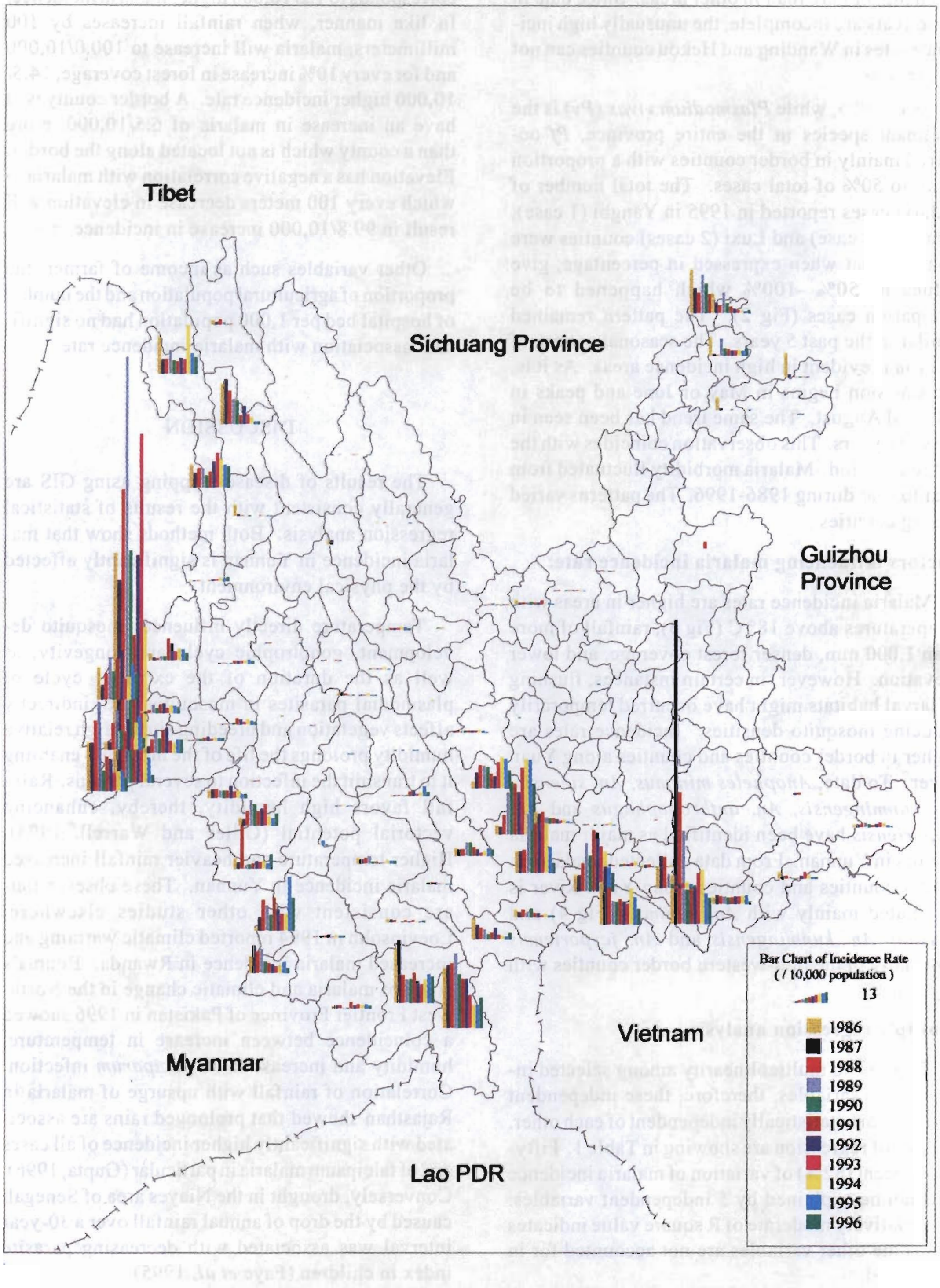

Fig 1–Annual malaria incidence rate Yunnan Province, China 1986-1996.

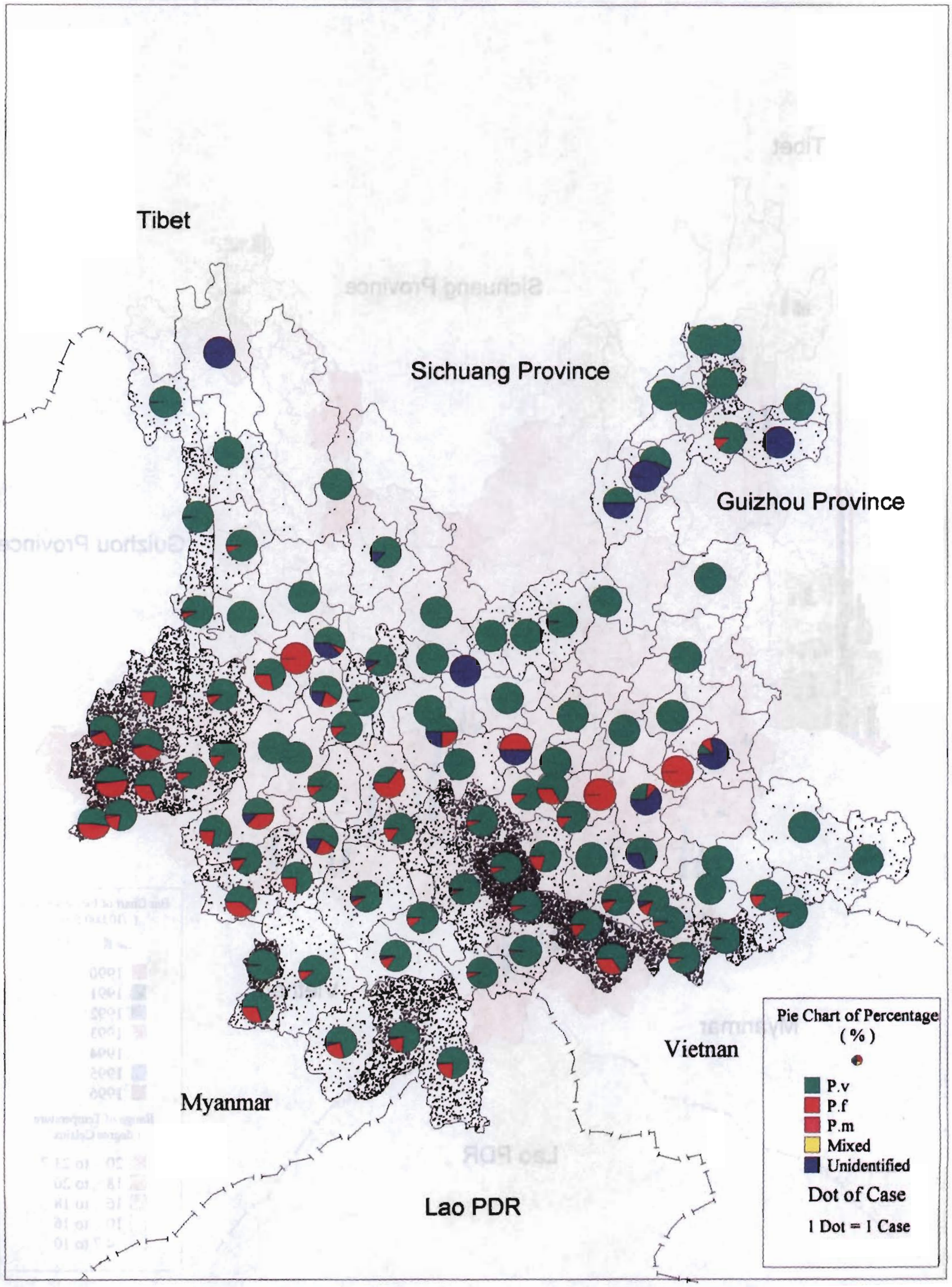

Fig 2–Malaria cases by parasite species Yunnan Province, China 1995.

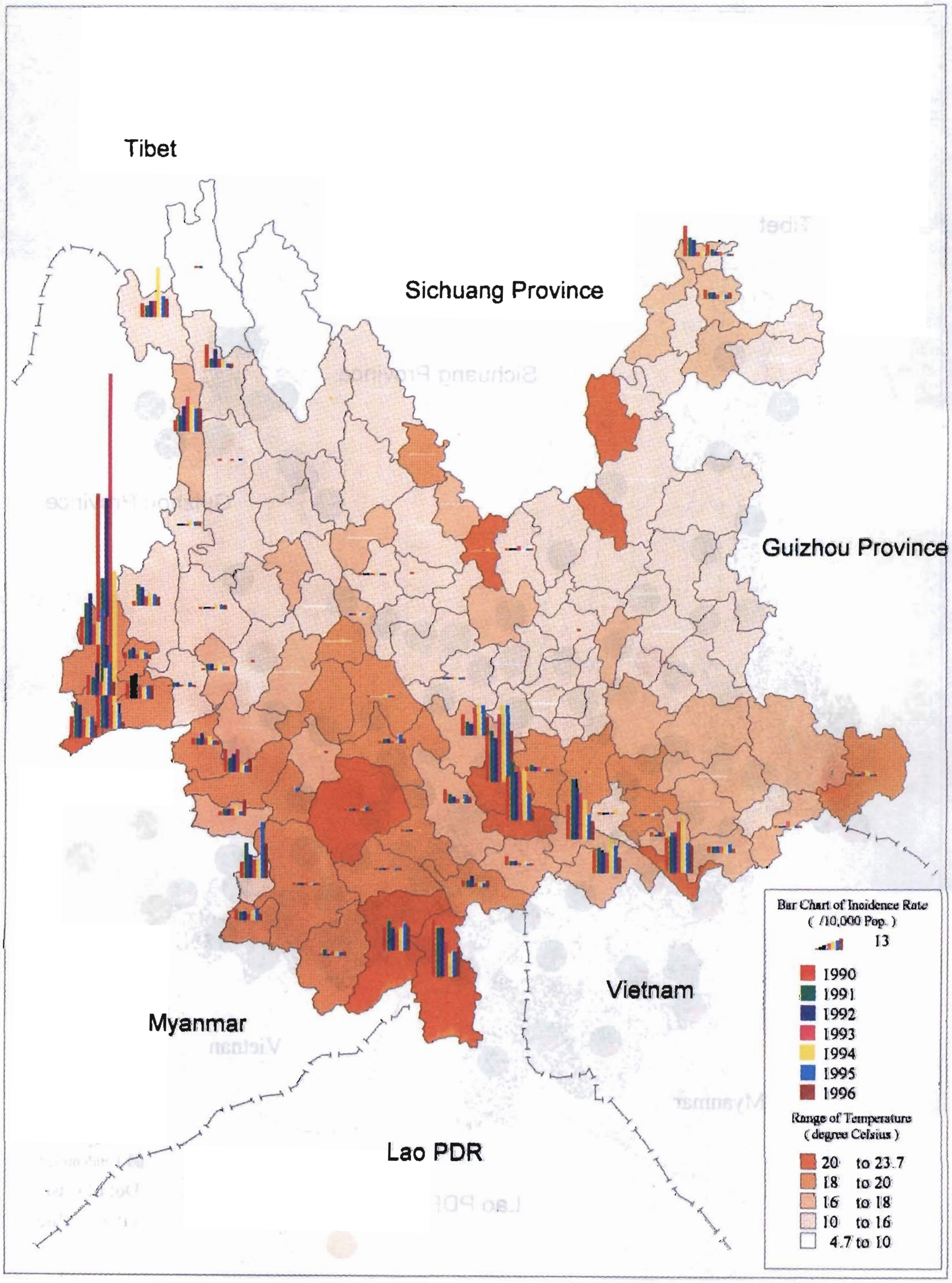

Fig 3–Annual malaria incidence rate and average annual mean temperature Yunnan Province, China 1990-1996.

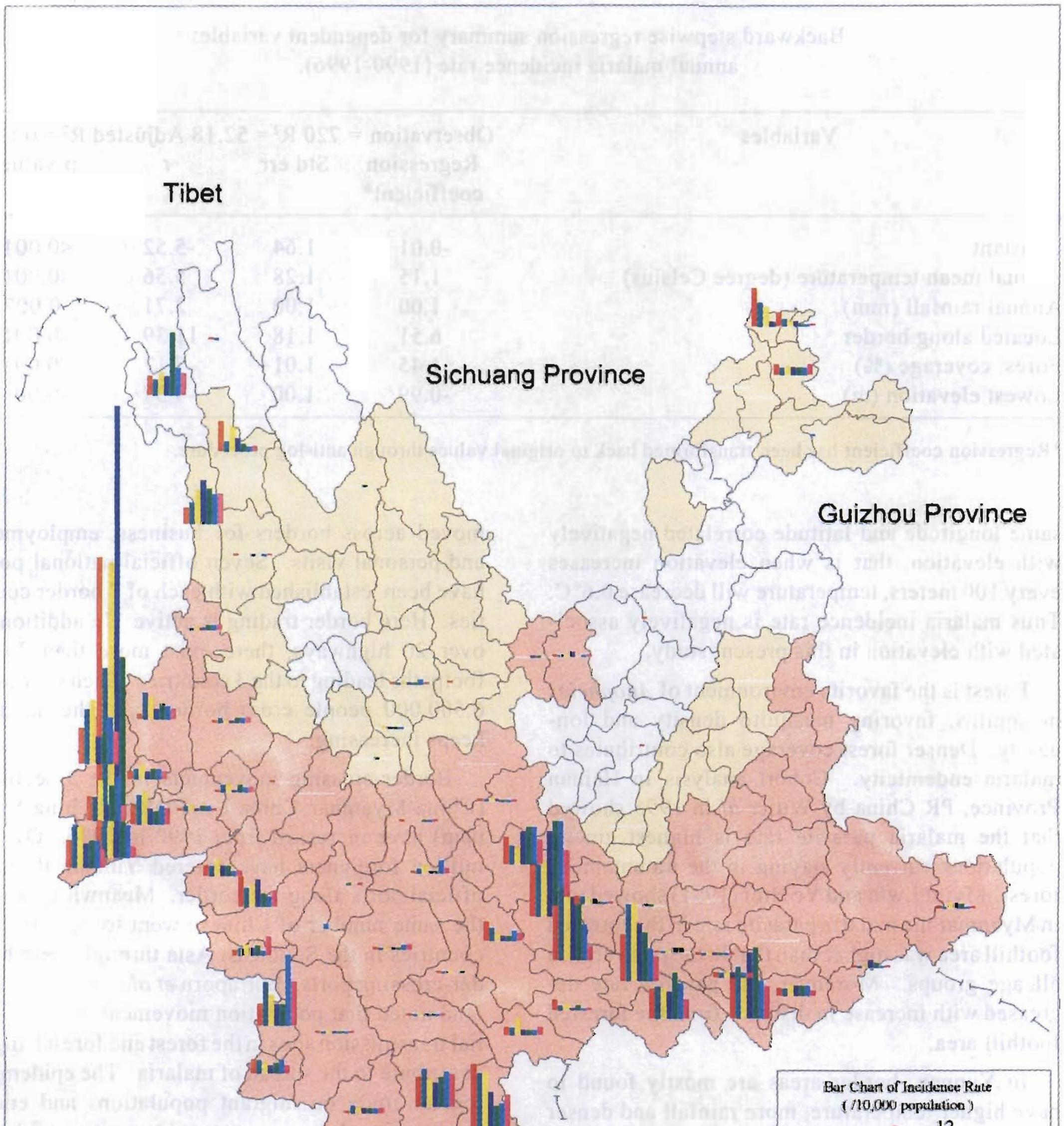

Fig 4–Annual malaria incidence rate and distribution of *An. minimus* Yunnan Province, China 1990-1996.

Table 1

Backward stepwise regression summary for dependent variable: annual malaria incidence rate (1990-1996).

Variables	Observation = 720 $R^2 = 52.18$ Adjusted $R^2 = 0.51$			
	Regression coefficient*	Std err	*t*	p-value
Constant	-0.01	1.64	-5.52	<0.001
Annual mean temperature (degree Celsius)	1.15	1.28	5.56	<0.001
Annual rainfall (mm)	1.00	1.00	2.71	0.007
Located along border	6.51	1.18	11.39	<0.001
Forest coverage (%)	1.45	1.01	7.17	<0.001
Lowest elevation (m)	-0.99	1.00	-9.37	<0.001

*Regression coefficient has been transformed back to original values through anti-log procedure.

same longitude and latitude correlated negatively with elevation, that is when elevation increases every 100 meters, temperature will decrease 0.6°C. Thus malaria incidence rate is negatively associated with elevation in this present study.

Forest is the favorite environment of *Anopheles* mosquitos, favoring mosquito density and longevity. Denser forest coverage also contributes to malaria endemicity. Cohort analysis in Hainan Province, PR China by Wu *et al* in 1995 showed that the malaria parasite rate is highest among populations currently staying in the mountainous forest. Myint Lwin and Ye Htut (1991) showed that in Myanmar the malaria parasite rate in the forested foothill area was higher than that in the plain area in all age groups. Moreover, the parasite rate decreased with increase in distance from the forested foothill area.

In Yunnan, border areas are mostly found to have higher temperature, more rainfall and denser forest as well as lower elevations, with an efficient vector - *An. minimus,* coinciding with higher incidence of malaria. As shown by regression analysis, additional factors other than physical environment must be present in border counties which contribute to higher malaria incidence. One of these is border-crossing population movement. The border linking Yunnan to 3 countries in Southeast Asia falls in the tropical zone. Local residents on both sides share similar cultures, life styles and even language. They usually have relatives on either side and have frequent contacts. With the extension of the open policy of PR China, more people have moved across borders for business, employment and personal visits. Seven official national ports have been established with each of 7 border counties. Here border trading is active. In addition to over 20 highways, there exist more than 2,000 footpaths leading to the 3 countries. Each year over 6,500,000 people cross borders and the number keeps increasing.

Border-crossing movements in the 3 sections (China-Myanmar, China-Lao PDR and China-Vietnam) have increased from 1990 to 1996. Over 4 million foreigners have entered Yunnan through official ports along the border. Meanwhile, about the same number of Chinese went to neighboring countries in the Southeast Asia through these border-crossing ports. Butraporn *et al* (1995) in Thailand noted that population movements into potential transmission sites in the forest and forest fringes contribute to the spread of malaria. The epidemiological study on migrant populations and endemicity of malaria in metropolitan cities of India showed that migrants from areas of high malarial endemicity who went into the metropolitan cities to take up employment were important sources of infection for the indigenous urban population (Sethi, 1990).

Sevilla-Casas (1993) indicated that malaria is concentrated in the delta zone of the Naya river basin where the influx of people into this zone for economic reasons occurs at a time when vector density was high. High human density combined with high vector density ensures continuous and intense transmission of malaria. Pryce *et al* (1993) observed that the number of travelers to Kenya has doubled in the 4 years studied and that the quarterly rates varied 4-fold over this period. As the popularity of East Africa as a tourist destination continues to increase, Kenya will remain an important and significant source of malaria imported into other countries such as the UK. Wang *et al* (1993) reported that blood examination conducted at border-checking points showed that the infection rate among border residents of Myanmar and Lao PDR were 5.4 and 7.2 times higher than that of Yunnan. Malaria incidence rates of Chinese entering Myanmar and staying overnight were 6.3% for one night, 18.2% for two nights and 31.0% for 3 nights, respectively.

Last (1987) stated that poverty is a risk factors for malaria, with people living in poor quality housing and unhygienic surroundings and often having inferior diets that are nutritionally inadequate. Moreover they are often separated by a greater social and geographical distance from health care facilities. Low income and higher prevalence of disease are strongly and positively correlated both in developed and developing countries. Study conducted by Gamage-Mendis *et al* (1991) indicated that higher malaria risk is associated with poorly constructed houses. Subramanian *et al* (1991) found that people residing in thatched houses with incomplete ceiling were exposed to greater risk of contracting malaria infections when compared to tiled houses. However, this relationship was not found in this present study due to lack of comprehensive data for analysis.

Malaria occurs mainly in rural areas in Southeast Asia where people live in poor surroundings, usually close to vector breeding sites. Working in foothill, forest and forest fringe areas exposes them to the bites of infected mosquitos. This study does not show a clear relation between a larger proportion of agricultural population and higher malaria incidence rate.

An. minimus is widely distributed in Yunnan; the question is why does it serve as a vector only in the southern part of the Province? Furthermore, the presence of *An. dirus* and if so, its role in malaria transmission in border areas in Yunnan remains to be studied. Current methods of detecting infected vectors such as dissection of mosquitos for sporozoites an/or oocysts may not be sensitive enough. Modern technics such as PCR, DNA probes, etc could confirm the occurrence of sibling species which may actually represent non-vector species. Because sibling species are morphologically identical by routine microscopic examination, the use of new biotechnology tools and cytogenetic analysis are needed to assess the vectorial status of mosquito species in Yunnan.

In conclusion, from the data so far collected, the malaria situation in Yunnan Province as a whole is influenced mainly by the combined effects of the physical environment and the presence of efficient vector species. In general, the incidence of cases varies according to season and geographic location, however, the level of endemicity of malaria in counties along borders and Yuan River is much higher than the rest of the province because of additional exacerbating factors such as population movements across international borders and between counties.

In line with the Global Malaria Control Strategy, the goal of malaria control in Yunnan Province should be to reduce morbidity and mortality to a level that can be sustained by existing malaria control measures. This depends on a large extent on adequate and continuing government support and the participation of all sectors.

Since malaria is a serious public health problem along international borders in Southeast Asia, there is an urgent need to develop the capacities of institutions and work forces on both sides to apply appropriate intervention measures against further deterioration of the malaria situation in these areas. Concerted action of all sectors involved is essential so long as adequate inter-country cooperation, necessary knowledge and skills, material, and human resources are in place.

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