CHAPTER TWO

Feasibility and Roadmap Analysis for Malaria Elimination in China

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Abstract

To understand the current status of the malaria control programme at the county level in accordance with the criteria of the World Health Organisation, the gaps and feasibility of malaria elimination at the county and national levels were analysed based on three kinds of indicators: transmission capacity, capacity of the professional team, and the intensity of intervention. Finally, a roadmap for national malaria elimination in the People's Republic of China is proposed based on the results of a feasibility assessment at the national level.

1. INTRODUCTION

With the articulation of the United Nations Millennium Development Goals, global malaria control has received growing attention from the international community (Committee and Secretariat, 2012; Dye et al., 2013). Considerable progress has been made in global malaria control, with malaria morbidity and mortality effectively reduced in some countries, and hence, malaria-endemic areas have shrinked (Bhaumik, 2013). With the progressive move from malaria control to elimination, the World Health Organisation (WHO) released guidelines to support countries aiming for malaria elimination (Kelly et al., 2012; Mendis et al., 2009; WHO, 2007). According to WHO guidelines, a blood slide positivity rate (SPR) among febrile patients lower than 5% is an indicator of preelimination, while an annual parasite incidence (API) among the at-risk population for 3 consecutive years without local infection below 1 per 1000 indicates achievement of the elimination stage (Clements et al., 2013; Cotter et al., 2013).

A serious threat to public health, malaria is a major parasitic disease hindering socioeconomic development in the People's Republic of China (P.R.China) (Diouf et al., 2014; Laurentz, 1946; Tang et al., 1991). Since the founding of P.R. China in 1949, governments at all levels attached great importance to prevention and control of malaria and made remarkable achievements (Zhou, 1981). For example, the incidence of malaria was reduced from more than 24 million cases in the early 1970s to tens of thousands in the late 1990s, which greatly narrowed the scope of endemic areas (Tang et al., 1991). Malaria due to *Plasmodium falciparum* infection was eliminated, with the exception of Yunnan and Hainan provinces. After 2000, malaria reemerged in some areas

(Gao et al., 2012; Zhou et al., 2012). However, with the implementation of the 2006–2015 National Malaria Control Programme (NMEP), increased support provided by the central and local governments improved the malaria control status. By 2009, the national incidence of malaria dropped to 14,000 cases, and the incidence rate was lower than 1 per 10,000 in 95% of the counties (cities, districts) in 24 malaria-endemic provinces (autonomous regions and municipalities) (Zhou et al., 2011). The incidence rate was above 1 per 10,000 in only 87 counties, indicating that P.R. China has marched into the preparation stage of elimination (Yin et al., 2013b).

However, malaria elimination still faces many challenges in P.R. China. First, some areas of the country are still seriously endemic, such as border areas of Yunnan province adjacent to Myanmar (Bi et al., 2013). Second, elimination of malaria is a new public health task, so the government has no previous experience and weak capacity in the low- or medium-endemic areas, especially in resource-constrained settings (Xu and Liu, 2012). Third, in a global economy with a mobile population due to trade, tourism and labour migration, there are constant opportunities for imported malaria cases, which are likely to generate local transmission (Pindolia et al., 2012). Fourth, technical bottlenecks are another obstacle on the way to malaria elimination (Yan et al., 2013; Yin et al., 2013a). For example, microscopy could not meet the demands of population surveillance in the malaria elimination stage because it is labour- and time-consuming (Zheng et al., 2013).

It is essential to understand the current status of the malaria control programme in P.R. China, the relevant criteria of WHO, as well as the gaps and feasibility of malaria elimination at county and national levels (Anthony et al., 2012; Maharaj et al., 2012; Moonasar et al., 2013). This will provide more information for determining the roadmap of the national malaria elimination campaign in P.R. China based on feasibility assessments, with an emphasis on potential transmission risks, the capacity of the professional team and the intensity of intervention (Cotter et al., 2013; Kidson and Indaratna, 1998; Moore et al., 2008; Yang et al., 2010).

2. FEASIBILITY ASSESSMENT AT THE NATIONAL LEVEL

A feasibility assessment was an essential step before the initiation of a NMEP to understand the current status and future potential risks, which provide the basis for formulating the goals of the NMEP for a specific time frame (Diouf et al., 2014; El-Moamly, 2013; Zofou et al., 2014). A retrospective survey was conducted using data collected from the NMEP to draw the malaria pattern, potential transmission risks and institutional capacities. In-depth analyses were performed for the relationship between incidence and interventions at the provincial level to demonstrate the feasibility of malaria elimination in different settings and to come forward with a national strategy for P.R. China.

2.1 Data sources

The data were collected from several sources. Information on malaria incidence during 1950–2010 was collected from the national database on infectious diseases. Demographic data were extracted from the *China Statistical Yearbook* (NBSC, 2012). Malaria case information during 2004–2011 (e.g. age, sex and occupation) was collected from the national information and reporting system for infectious diseases (Wang et al., 2008). The *National Annual Report on Schistosomiasis, Malaria and Echinococcosis,* published by the Chinese Center for Disease Control and Prevention (Jin et al., 2006), provided malaria incidence and intervention data collected in each province by year during 2004–2010. Intervention data included information on radical treatment in the pretransmission stage (RTPT), indoor residual spraying (IRS), populations protected by insecticide-treated nets (ITNs), and training of microscopists, vector control staff, epidemiologists and other specialists (Zhao et al., 2013; Xia et al., 2014).

In addition, a database was established using data collected from 24 endemic provinces in 2010 through a questionnaire survey, including transmission risks and elimination capacities at the county level (Zhou et al., 2014). The information on transmission risks included data on malaria transmission risk with morbidity and vector species, while the data on elimination capacities included such information as whether a leading group was established, whether an implementation plan was issued, funding, personnel, supervisions, microscopic examination stations, active case detections, coverage of the reporting system, foci investigations and health education.

2.2 Assessment indicators

All quantitative data indicators were divided into five categories after being weighted by the county population. Those assigned values revealed the different levels of importance (El-Moamly, 2013). Four determinants were used in the assessment, including the incidence of malaria in each county, the value of the transmission capacity of vector species, the malaria transmission risk index for each county and the malaria elimination capability index. The actual value of the last two indices—employing the malaria transmission risk index (MTRI) and malaria elimination capacity index (MECI)—were converted to a uniform dispersion ratio of magnitude through standardised deviation, deviation normalised value = (variable value—min)/(max—min), so that those two indices could be compared among all counties equally (Zhou et al., 2014). For instance, the MECI assigned different weights to each county based on the ability to eliminate malaria weighted by a grade value of each indicator, of which the weighted values are summerised in Table 2.1.

By employing the MTRI, the MECI, and malaria incidence in 2010, a plot with three dimensions was generated to make a quantitative assessment of the potential risks to achieve the goal of the NMEP (Zhou et al., 2014). The different categories of potential risks were mapped at the county level, which will help to formulate the elimination strategy at the national level.

2.2.1 Malaria transmission risk index

The MTRI was defined the potential risk level for malaria transmission in a specific area. In one county, the MTRI = VTI × LPR, where VTI is the vectorial transmission index (defined as the vectorial capacity for transmission of malaria by *Anopheles* mosquito, the main local mosquito species for transmission of malaria) and LPR is the local potential risk for malaria transmission (defined as the potential malaria transmission risk at local level or county level, based on the malaria prevalence in the previous 3 years from 2007 to 2009). The detailed calculations of those indices as well as the weight values are listed in Table 2.1 (Zhou et al., 2014).

2.2.2 Malaria elimination capacity index

The MECI is defined as the local administrative ability devoted to the NMEP, weighted by the ability for data management, intervention work plan in 2010, organisational management, surveillance system, inspection, monitoring and evaluation, mobilisation, prevention for imported cases and financial input (Table 2.1). The calculation formula is as follows:

MECI = data management × 5 + intervention work-plan in 2010 × 6 + organisational management × 4 + surveillance system × 8 + inspection × 6 + mobilisation × 5 + monitoring and evaluation × 8 + prevention for imported cases × 10 + financial input × 9 (Zhou et al., 2014).

2.2.3 Risk of malaria transmission in a population

Malaria case distribution during 2004–2011 is shown in Figure 2.1. During 2004–2011, a total of 237,513 cases of malaria were reported, among which 158,206 were male (66.6%) and 79,307 were female (33.4%). The

Table 2.1 The calculation of indices and their weighted values

Index	Definition	Weight value[a]
Vectorial transmission index (VTI)	VTI is defined as the vectorial capacity for transmission of malaria by the *Anopheles* mosquito, the main local mosquito species for transmission of malaria. These mosquito species in P.R. China include *Anopheles dirus*, *An. jeyporiensis candidiensis*, *An. minimus*, *An. lesteri anthropophagus*, *An. sinensis* and *An. pseudowillmori*	*An. dirus*: 6 *An. jeyporiensis candidiensis*: 5 *An. minimus*: 4 *An. lesteri anthropophagus*: 3 *An. sinensis*: 2 *An. pseudowillmori*: 1
Local potential risk for malaria transmission (LPR)	LPR is defined as the potential malaria transmission risk at the local level (or a county), based on the judgement of malaria prevalence in the previous 3 years (from 2007 to 2009). A total of four strata were classified: stratum 1 is the area where annual malaria prevalence is more than 1 per 100,000 in each of the 3 years; stratum 2 is the area where annual malaria prevalence is more than 1 per 100,000 in at least 1 during 3 years; stratum 3 is the area where malaria prevalence is less than 1 per 100,000 during 3 years; and stratum 4 is the area where no local cases were found during 3 years.	Stratum 1: 10 Stratum 2: 7 Stratum 3: 4 Stratum 4: 1
Malaria elimination capacity index (MECI)	MECI is defined as the local administrative ability devoted to the NMEP, weighted by ability in data management, intervention work plan in 2010, organisational management, surveillance system, inspection, mobilisation, monitoring and evaluation, prevention for imported cases and financial input.	Data management: 5 Intervention work plan in 2010: 6 Organisational management:4 Surveillance system: 8 Inspection: 6 Mobilisation: 5 Monitoring and evaluation: 8 Prevention for imported cases: 10 Financial input: 9

[a]Note: Weight values were granted based on the importance of achieving the goal of the NMEP, based on Delphi analysis (details of the Delphi analysis are reported elsewhere).

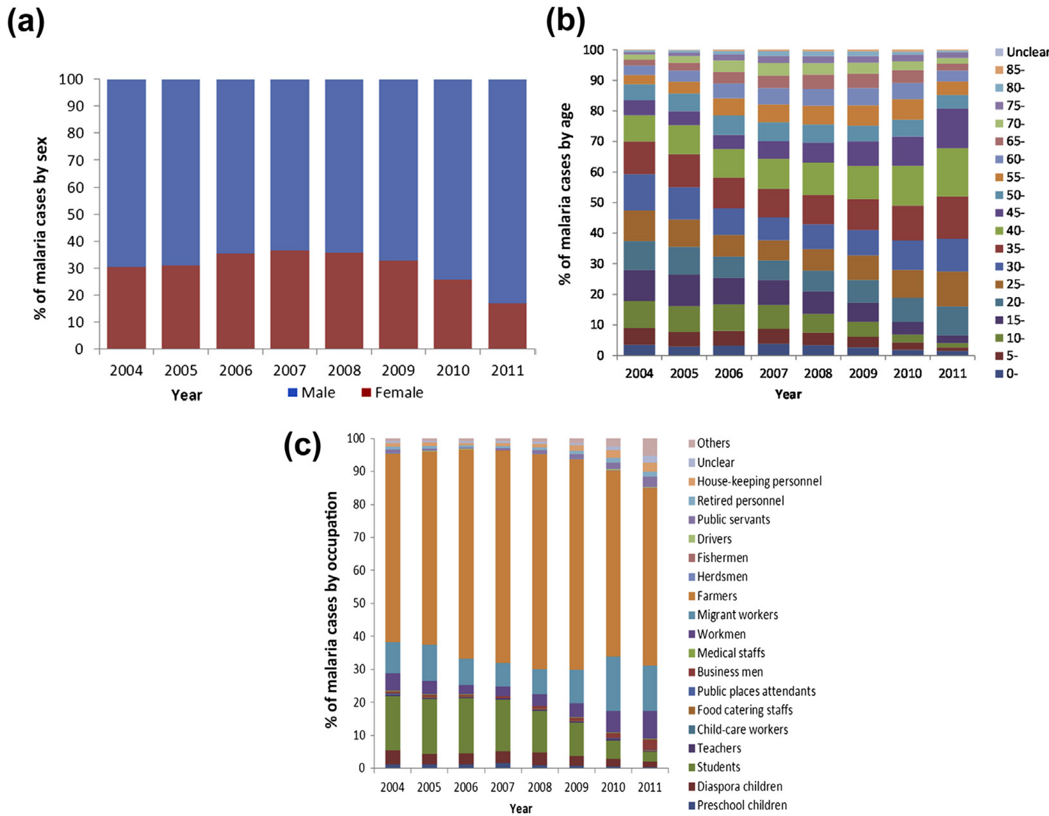

Figure 2.1 The characterisation of malaria cases in P.R. China during 2004–2011. (a) Malaria distribution stratified by sex; (b) malaria distribution stratified by age; (c) malaria distribution stratified by occupation.

ratio of male to female was 1.99:1. Among the reported 237,513 cases, the 10- to 50-year-age group was predominant, accounting for 66.7% of the total number, while the proportion of children under 5 years of age was only 3.3%. The proportion of the 20- to 45-year-old age group tended to increase. The majority of cases were farmers, students and migrant workers, accounting for 61.6%, 14.9% and 9.0% of the total number, respectively, which was 85.5% in total. Among them, the proportion of workers and government staff increased over time from 2004 to 2011.

3. CORRELATION BETWEEN INCIDENCE PATTERNS AND INTERVENTIONS IN FOUR TARGET PROVINCES

To understand the impact of the intervention on the reduction of malaria incidence at the local level, correlations between incidence patterns and interventions were calculated in two typical transmission areas at the provincial level.

3.1 Historical transmission pattern of four provinces

Four typical provinces – Anhui, Henan, Yunnan and Hainan – were selected to represent two typical patterns of malaria transmission in P.R. China: (1) high transmission areas with *P. vivax* singly in central P.R. China; and (2) high transmission areas with mixed *P. vivax* and *P. falciparum* in southern P.R. China. Two transmission features during the preelimination stage were presented with historical data collected from 2004 to 2010 (Zhang et al., 2014). First, the general transmission pattern showed that a total of 244,836 malaria cases were reported in P.R. China from 2004 to 2010, and 88% of all cases were from four target provinces: Anhui (accounting for 44% of the total cases), Henan (8%), Yunnan (26%) and Hainan (10%) provinces (Pan et al., 2012; Zhou et al., 2012). Second, only *P. vivax* malaria was distributed in Anhui and Henan provinces during the last decade, while both *P. vivax* and *P. falciparum* malaria occurred in Hainan and Yunnan provinces (Lin et al., 2009; Xu and Liu, 2012).

P. vivax malaria incidence was highest in Hainan (0.098%) and in Anhui (0.064%) in 2004 and in 2006, and then gradually declined annually to 0.09 and 0.28 per 10,000 in 2010, respectively. In Yunnan and Henan, the peaks of *P. vivax* malaria incidence were in 2005 and 2006, respectively, which were substantially below that in Hainan and Anhui provinces (Xia et al., 2012; Xia et al., 2014). Similarly, incidences in the two provinces decreased to 0.60 and 0.11 per 10,000 in 2010 (Figure 2.2). The incidence of *P. falciparum* malaria in Hainan was relatively higher than that in Yunnan

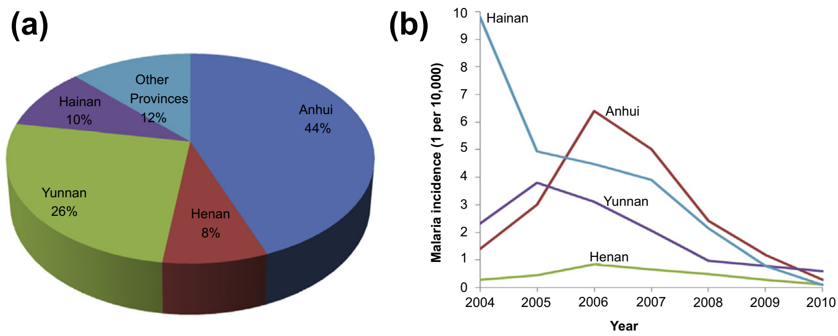

Figure 2.2 Malaria incidence in the four top provinces of Anhui, Henan, Yunnan and Hainan from 2004 to 2010. (a) Proportion of total number of malaria cases by provinces; (b) *P. vivax* malaria incidence for each of four provinces (Xia et al., 2014).

during 2004–2005, but it dropped quickly to zero local cases in 2010. However, the local incidence of *P. falciparum* malaria in Yunnan remained at a certain level with little reduction, to 0.03 per 10,000 (Lin et al., 2009; Wang et al., 2012; Xiao et al., 2012).

3.2 Correlation between malaria incidence and interventions

The correlation between incidence and interventions in four target provinces was calculated based on the time-series cross-sectional (TSCS) data model (Gmel et al., 2001; Reibling, 2013). The detailed process for TSCS data modelling is described in Appendix 1. Results showed that three scenarios could be observed.

First, generally, the TSCS data model showed that provincial differences in the annual incidence of malaria were mainly due to two interventions: RTPT for populations who were either historical cases or at-risk and the application of ITNs. The incidence of malaria differed among the four provinces, mainly because of antimalarial treatment variations: Yunnan was the highest, followed by Hainan, with Henan being the lowest ($F = 15.19$, $p < 0.001$, $R^2 = 0.724$). As a result of the use of ITNs, Hainan was the highest, followed by Yunnan, whilst Henan showed lowest ($F = 16.77$, $p < 0.001$, $R^2 = 0.689$) (Xia et al., 2014). These data indicate that both RTPT and ITNs are important interventions explaining the observed reduction of malaria transmission in Yunnan and Hainan provinces (Cao et al., 2013).

Second, in the correlation analysis between *P. vivax* malaria incidence and various interventions, results showed that two interventions – RTPT among historical patients or at-risk populations and microscopy training – influence the variation of *P. vivax* malaria incidence among the four provinces. For *P. vivax* malaria treatment ($F = 14.53$, $p < 0.001$, $R^2 = 0.721$), Hainan is the highest, followed by Yunnan and then Anhui, with Henan being the lowest. For microscopy training ($F = 11.53$, $p < 0.001$, $R^2 = 0.609$), Hainan is the highest and Henan is the lowest (Xia et al., 2014). These data indicate that antimalaria treatment and capacity in diagnosis are the key factors in the control of *P. vivax* malaria (Xu et al., 2002).

Third, in the correlation analysis between *P. falciparum* malaria incidence and intervention measures, two interventions were significant factors: microscopy training ($F = 11.06$, $p < 0.001$, $R^2 = 0.870$) and vector control training ($F = 15.28$, $p < 0.001$, $R^2 = 0.895$) (Xia et al., 2014). These data indicate that measures integrating treatment with strengthened capacity in diagnosis and vector control are of importance in the control of *P. falciparum* malaria transmission (Tambo et al., 2012).

3.3 Effective intervention during the transition stage from control to elimination

To understand the changes of intervention in the transmission stage from control to elimination, we consider a case study of the two typical patterns of malaria transmission in P.R. China. In the first type of transmission pattern, malaria transmission in Henan province was at the lowest level (0.11 per 10,000) of incidence in history (in the year 2010), reaching the threshold of entering the elimination stage according to WHO criteria. In the second type of transmission pattern in Hainan province, no *P. falciparum* malaria cases were found and *P. vivax* malaria incidence was 0.09 per 10,000 in 2010, which also reached the threshold of entering the elimination stage according to WHO criteria (Committee and Secretariat, 2013a).

In Henan province, where only *P. vivax* malaria is transmitted, the interventions of RTPT for historical patients and at-risk populations and the application of ITNs were effective measures for clearing the infection sources. These interventions had spatial and temporal characteristics based on the results of correlation analysis (Chen et al., 2012; Liu and Xu, 2006; Xu et al., 2006). In addition, to further reduce the incidence, strengthened training to improve the diagnostic capacity of malaria microscopy helps in the timely detection and treatment of malaria so as to control malaria transmission (Bi et al., 2012; Fernando et al., 2013; Huang et al., 1988).

In Hainan province, where both *P. vivax* and *P. falciparum* malaria were transmitted in recent years, an RTPT intervention for malaria patients and the at-risk population, together with strengthened capacity for microscopy diagnosis and vector control, were effective measures (Dapeng et al., 1996). Specifically for vector control, the application of ITNs was effective, while IRS was ineffective. This is because the major mosquito species for transmission of malaria is *An. dirus*, which is mainly found outdoors in the mountainous area of Hainan province (Wang et al., 2013).

In conclusion, RTPT for historical patients and at-risk populations during the pretransmission season (normally from February to April) and application of ITNs were effective measures in the transition stage from control to elimination of malaria. The cost-effectiveness of the interventions will be improved when the capacity for diagnosis and vector control are strengthened at the same time (Roy et al., 2013; Wang et al., 2012; Zheng et al., 2013).

4. FEASIBILITY ANALYSIS OF MALARIA ELIMINATION IN CHINA

To achieve malaria elimination in a large country like P.R. China, there are many challenges to address. Those challenges must be identified and addressed with the progress of the NMEP (El-Moamly, 2013). Therefore, a feasibility analysis of the potential to achieve the goal of the malaria elimination is essential at the beginning of the NMEP, with a focus on the natural and biological risks in the transmission and intervention capacities at the local level (Clements et al., 2013).

4.1 Transmission risks

The feasibility analysis of transmission risks was conducted in a total of 2147 counties targeting elimination in P.R. China based on the goals of the NMEP (Cao et al., 2013; Yang et al., 2012). The MTRI (see Section 2.2.1) varied from 0 to 60, with an average of 50.8. Geographically, higher MRTIs tended to be distributed in the south, whereas lower MRTIs were located in north P.R. China.

When we analyse the MRTI for four typical transmission provinces, its average value is the highest in Hainan province (23.6), followed by Yunnan (22.9), Anhui (9.0) and Henan (5.6) provinces.

4.2 Malaria elimination capacities

The MECI (see Section 2.2.2) for each of 2147 counties was composed of nine variables. The average MECI value among these 2147 counties was 221.4, varying from 23 to 895. Among the four provinces studied, it was the highest in Yunnan province (915.1), followed by Anhui (363.2), Hainan (349.8) and Henan (313.4) provinces. All of these MECIs exceeded the

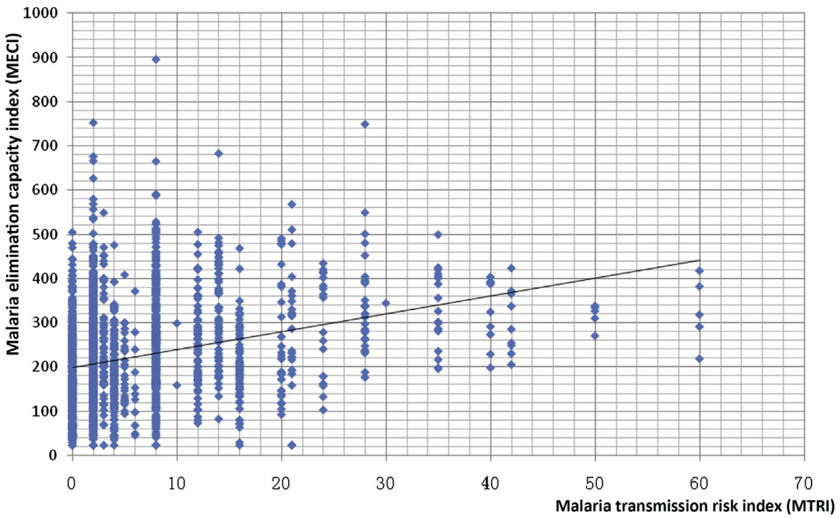

Figure 2.3 Correlation diagram between county-level malaria transmission risk index (MTRI) and malaria elimination capacity index (MECI) for 2147 counties (Zhou et al., 2014).

average value of the whole country. Among the nine variables, two types could be identified: the technical capacity, which can be improved by training, and the resource capacity, which can be increased through the political awareness of policymakers. Figure 2.3 shows that the MECI in 40% of the counties was below average, indicating that the capacities in those counties should be strengthened in order to achieve the goal of the NMEP by 2020.

4.2.1 Technical capacity

The technical capacity included five variables: (i) data management; (ii) intervention work plan in 2010; (iii) inspection; (iv) monitoring and evaluation; and (v) prevention for imported cases. The best way to increase the technical capacity is to strengthen the training activities or technical practice in technical organisations involved in malaria elimination, such as county centres for disease control and prevention, township hospitals and village clinics.

4.2.2 Resources capacity

Resources capacity covered four variables: (i) organisational management; (ii) surveillance systems; (iii) mobilisation; and (iv) financial input. In the areas that previously experienced large epidemics of malaria, county governments can easily maintain the necessary capacity, but it is normally difficult to increase or maintain the awareness of local governments in the counties where transmission was at low levels for a long time. Therefore, in order to maintain this kind of resource capacity, regulations to mitigate the potential risks of malaria transmission locally in each county are likely to be enforced.

4.3 Feasibility analysis for malaria elimination at the national level

4.3.1 Feasibility analysis employed by MTRI and MECI

The correlation diagram between MTRI and MECI for each county is shown in Figure 2.3, where 85% of counties have MTRI below 20 and MECI below 30. Therefore, counties where MTRI is above 20 need to be monitored rigorously.

4.3.2 Feasibility analysis employed by malaria incidence, MTRI and MECI

A total of 2147 counties were mapped in a three-dimensional figure with four categories (in different colours) of counties based on malaria incence (MI), MTRI and MECI (Figure 2.4).

Figure 2.4 shows that MI rates in the majority of counties are zero, although their MTRI varied from 0% to 20% and MECI varied from 0% to 30%. A few of the counties located in the blue zone are of higher incidence (MI > 1 per 1000 and <1 per 10,000), which is a potential risk area, probably due to the introduction of imported cases from other regions or countries.

4.3.3 Feasibility analysis with geographic variations

When all counties were mapped using these four categories, the spatial distribution of each type of county provided information for decision makers to formulate elimination strategies with certain resources in each region (Figure 2.5). Figure 2.5 indicates that the counties in stratum 1 are distributed along either county borders or provincial borders. Therefore, for malaria elimination in the last stage, close attention must be paid to the border areas, with enhanced capacity building for sustained surveillance and response.

In historical reports on the progress of the national malaria control campaign, malaria stratification has been carried out at the county level. For example, according to the research conducted by Ho Qi and Feng Lanzhou in 1958, malaria endemic areas can be divided into four

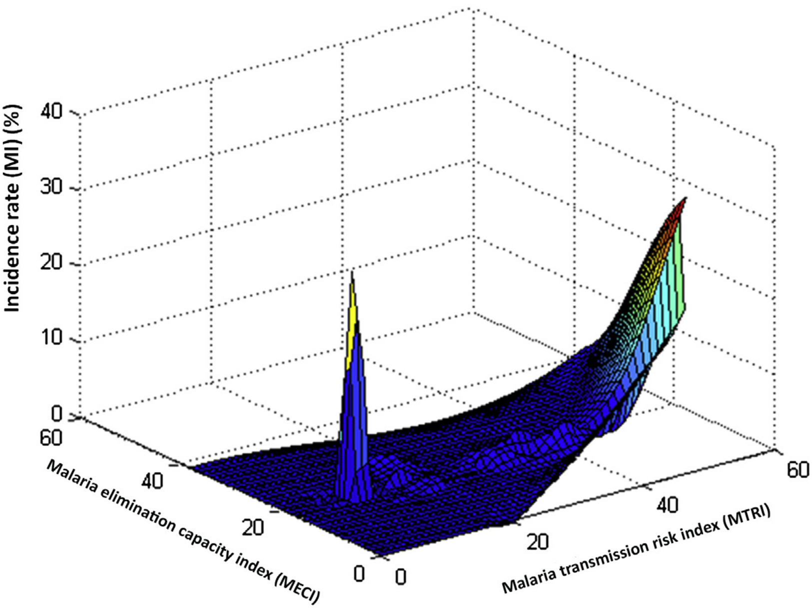

Figure 2.4 A three-dimensional plot employing three variables (MTRI, MECI and MI) showing four strata of counties among all 2147 studied counties (Zhou et al., 2014). Stratum 1 areas are shown in red, located in the top right, with a high local vector capacity (MTRI = 50–60), of which malaria elimination capacity is at the middle level (MECI around 20) and malaria incidence is higher (MI > 1 per 10,000). Stratum 2 areas are shown in green, where high transmission risk (MTRI = 50–60) was present, the local antimalarial capability was at the lower or middle level (MECI = 10–30) and the incidence rate was less than that of stratum 1 (MI > 1 per 1000 and < 1 per 10,000). Stratum 3 areas are shown in yellow, where malaria transmission risk index is low (MTRI around 10), MECI is at the middle level (around 20) and the incidence rate is close to that in stratum 2 (MI > 1 per 1000 and <1 per 10,000). Stratum 4 areas are shown in blue, where both the transmission risk and control capacity index are at low levels (MTRI and MECI = 0–40) and malaria incidence rate decreased with the significant decrease of MTRI and MECI. (For interpretation of the references to color in this figure legend, the reader is referred to the online version of this book).

regions based on splenomegaly rate, protozoa species and media distribution, terrain, climate and other factors combined with the latitude and longitude location of endemic areas (Ho and Feng, 1958; Zhou, 1991). In 1965, unstable and stable areas were proposed by Ho Chi (Ho, 1965). In 1995, Liu Zhaofan divided malaria endemic areas into four clusters according to vector distribution and incidence with reference to natural and geographical profiles (Liu et al., 1995b). In 2007, the NMCP

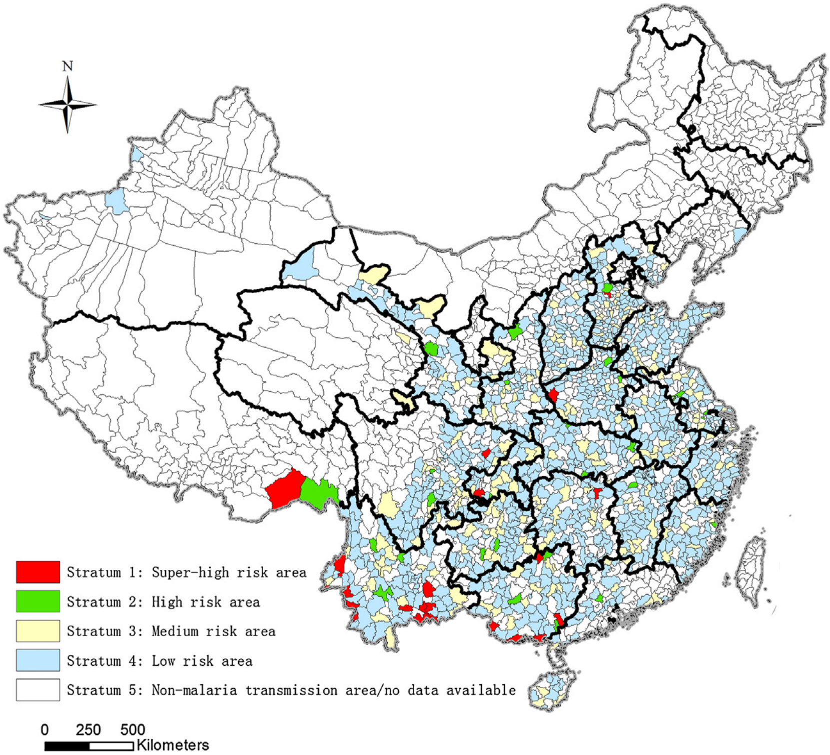

Figure 2.5 Map of counties at potential risk for malaria, showing four different categories of counties with geographic distribution patterns (Zhou et al., 2014).

divided malaria-endemic areas into three areas: (i) high transmission; (ii) unstable transmission; and (iii) under control regions (MOH, 2007).

However, these classification methods are mainly based on vector distribution and the level of malaria incidence. Additionally, malaria stratification was never conducted at the county level in P.R. China. In addition to vector and incidence, malaria transmission risk is also relevant to control capacity (Committee and Secretariat, 2013b; Cui et al., 2012). In the elimination phase, with a dramatic decrease of incidence, it is not adequate to determine malaria risks based on incidence and vector data only.

In this study, considering the transmission risk and control capacities, malaria risk in 2010 was analysed at the county level, based on our proposed new method for malaria risk analysis. This approach could be used in P.R. China, and even other countries, to guide stratification of malaria transmission risk.

5. PHASE-BASED MALARIA ELIMINATION STRATEGIES

The WHO proposed that once malaria incidence is less than 1 case per 1000 population at risk annularly, a malaria elimination programme could be initiated (Bousema et al., 2012; Feachem et al., 2010). Since 1990, P.R. China's average malaria incidence rate at the country level has decreased to 1 per 10,000 annually. However, some locations are still heavily epidemic in specific ecosocial zones, with some outbreaks occurring from time to time. For instance, a malaria outbreak occurred in northern Anhui province in 2006 (Wang et al., 2009; Zhou et al., 2010). The Chinese NMEP was not launched until 2010, with the aim to eliminate malaria nationwide by 2020 (Zheng et al., 2013; Zhou et al., 2011). Nevertheless, taking consideration of the fact that transmission patterns and elimination capacities vary from county to county, malaria elimination strategies need to be identified based on local settings, such as at the county level in different phases of the national programme (Cao et al., 2013;Yang et al., 2012).

5.1 Classification of elimination phases

WHO guidelines divide malaria control into four phases (Moonen et al., 2010; WHO, 2007). Preelimination occurs when the incidence rate is less than 1 per 1000. As shown in this study, from an annual incidence of 1 per 1000 until elimination, malaria control could be further subdivided into the following stages under phases 2 and 3 of WHO classification (or preelimination and elimination phases) stage E1 between SPR<5% in fever patients and 1 per 1000 of incidence rate); stage E2 (incidence rate less than 1 per 1000, and over than 1 per 10,000); stage E3 (incidence rate less than 1 per 10,000); and stage E4 (0 local cases annually).

In stage E1, the annual incidence rate is over 1 per 1000 and transmission capacity is still high; this is equivalent to the preelimination phase in the WHO classification. All stratum 1 areas in the Chinese classification belong to this stage. In this stage E1, transmission control is the main task. In stage E2 the annual incidence rate is between 1 per 1000 and 1 per 10,000 and malaria transmission tends to be stable. This stage E3 is equivalent to the start of elimination phase of the WHO classification and strata 2–3 of the Chinese classification, in which interventions focus on clearing the source of infection by case management and improving control capacities towards elimination. In stage E3, the annual incidence rate is less than 1 per 10,000 and malaria transmission maintains at very low levels, with sporadic distribution of malaria cases. This stage E3 is equivalent to the later elimination phase of the WHO classification and stratum 4 of the Chinese classification, in which the intervention is focused on surveillance and response to preventing imported cases. In stage E4, the annual incidence approaches 0 and almost no local cases occur. This stage E4 is equivalent to the end point of elimination phase of WHO classification and stratum 5 of the Chinese classification, in which the surveillance and response systems is established and aims at prevention of reemergence of malaria due to imported cases (Figures 2.4 and 2.5).

5.2 Strategy formulations in each stage

Elimination strategies differ based on the transmission patterns in different phases of the NMEP. More stages of the elimination programme exist in the classification of the Chinese NMEP compared to the WHO classification. Therefore, more detailed elimination strategies are identified for each stage in the Chinese NMEP. For instance, from preelimination to posttransmission, there are only three phases in the WHO classification—the preelimination phase, the elimination phase and the posttransmission phase—until certification of malaria elimination in 3 years. The elimination phase is normally much longer, usually more than 5–10 years. Therefore, Chinese classification uses five stages, which are based on the indices of malaria transmission and control capability. Stage E1 is equivalent to the preelimination of WHO classification; stage E2 is equivalent to the WHO elimination phase in the early period; stage E3 is equivalent to the WHO elimination phase in the middle period; stage E4 is equivalent to the period of zero local cases in the later WHO elimination phase; and stage E5 is equivalent to the WHO posttransmission phase (Table 2.2).

In accordance with the five strata of malaria endemic areas in P.R. China, the elimination strategy varies from stratum to stratum. For instance, stratum 1 areas (shown in red in Figure 2.6) are mainly located in Yunnan, Hainan and Guizhou. In this important area to eliminate malaria, elimination interventions are comprised of (1) strengthening infection control integrated with vector control measures; and (2) improving control capabilities to reduce the risk of transmission. In stratum 2 (shown in green), these areas are mainly distributed in Yunnan, Hainan, Guizhou, Shaanxi, Hubei, Anhui and other provinces. Due to weak capacities, the elimination interventions are to (1) strengthen training to improve local abilities; and (2) appropriately control infection sources to consolidate malaria control efforts. In stratum 3 (shown in yellow), these areas are mainly scattered in Jiangsu, Zhejiang,

Table 2.2 Comparison of various strategies in the WHO and Chinese classifications

WHO classification	**Preelimination**	**Elimination**	**Postelimination**
Annual incidence	Slide or rapid diagnostic test positivity rate <5% in fever cases	<1 case per 1000 population at risk/year	Zero locally acquired cases for 3 years
WHO strategy	Reinforcing the coverage of good-quality laboratory and clinical services, reporting and surveillance aimed at halting transmission nationwide Perfecting the quality and targeting of case management and vector control operations, and introducing/maintaining activities aimed at consistently reducing the onward transmission from existing cases in residual and new active foci Establishment of a strong surveillance system, with the cooperation of all healthcare providers	Identification and treatment of all malaria reservoir and reduced transmission by vectors with full surveillance for clearing up malaria foci and reducing the number of locally acquired cases to zero Identifying and treating all malaria cases with efficacious antimalarial medicines against liver stage and blood stage parasites, including gametocytes Reducing human–vector contact and the vectorial capacity of the local *Anopheles* mosquito populations in transmission foci by efficacious vector control, personal protection and environmental management methods	Maintain an effective surveillance and response system and strengthen prevention and management of imported malaria to prevent introduced cases and indigenous cases secondary to introduced cases Reduction of vulnerability population Screening of immigrants for malaria and the use of radical treatment in places where importation of malaria is intensive

Chinese classification	**Stage E1**	**Stage E2**	**Stage E3**	**Stage E4**	**Stage E5**
Annual incidence	>1/1000	1/1000–1/10,000	< 1/10,000	0	0 locally acquired cases for 3 years
Chinese strategy	Strengthening infection control integrated with vector control measures Improving control capabilities to reduce the risk of transmission	Strengthen training to improve local abilities Appropriately control infection source to consolidate malaria control efforts	Strengthen the surveillance-response system Find and treat imported cases earlier	Strengthen surveillance, both active and passive, for early detection of infection sources	Strengthen the surveillance response system to prevent the reintroduction of malaria cases

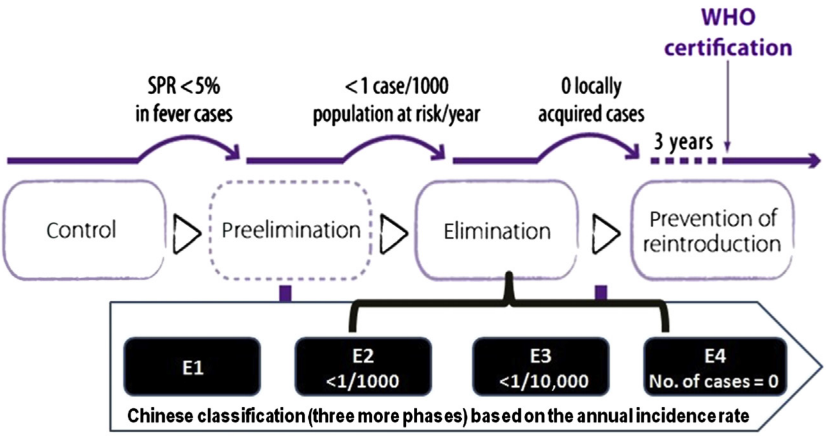

Figure 2.6 Integrated diagram of the malaria elimination stages and phases, indicating the four WHO phases of malaria elimination. Three more phases or stages were classified in our study based on the annual incidence rate: stage E1 is equivalent to the preelimination phase in the WHO classification; stage E2 is equivalent to the WHO elimination phase in the early period; stage E3 is equivalent to the WHO elimination phase in the middle period; stage E4 is equivalent to the WHO phase of zero local cases in the later elimination stage; and stage E5 is equivalent to the WHO posttransmission.

Sichuan, Hunan, Hubei, Henan and other provinces. Few of high incidences occur in these areas, mainly due to the higher numbers of imported malaria cases. Here, the elimination interventions aim to (1) strengthen the surveillance-response system; and (2) locate and treat imported cases earlier (Cao et al., 2013; Yin et al., 2013b). In stratum 4 (in blue), these areas are widely dispersed with sporadic distribution of malaria cases. The main intervention is to strengthen surveillance, both active and passive surveillance, to find the infectious sources earlier.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The history of the NMCP in P.R. China can be classified into two stages (MOPH, 1990). The first stage is from 1950 to 1980. Malaria was highly prevalent in this stage, fluctuating every 10 years with three peaks each time (Kung and Huan 1976; Zhou, 1981). The second stage started after 1980. Despite slight rebounds, no incidence peaks were found in this stage due to stable malaria control agencies at all levels, sustained control efforts, increased capacities and sustained interventions that reduced transmission risks significantly (Tang et al., 1991; Zhou, 1991). The setup of the national disease surveillance and reporting system allowed for individual cases to be reported nationwide since 2004 (Liu et al., 1995a). The population distribution of malaria cases nationwide from 2004 to 2011 showed an increasing proportion in the 20- to 45-year-age group, which might be attributed to the occupations of this population, including farming, business and production, which are more susceptible to infections (Tang, 2000; Zhou et al., 2010). Regarding occupational distribution, the proportion of farmers is the greatest but with a declining trend, while the proportions of mobile workers, businessmen and government staff have risen significantly. Particular increases have been noted in mobile workers who migrated back from African countries after working there for years (Jelinek and Muhlberger, 2005; Ming, 2008; Xia et al., 2012; Yin et al., 2013b; Zhang et al., 2010).

The classification approach used in P.R. China's Action Plan for Malaria Elimination (2010–2020) relies on the incidence at the county level during the period of 2006–2008, without considering the capacity of local institutions or vector capacities (Yang et al., 2012). This approach has provided useful information for designing the strategy used in the initiation of the NMEP, but it does not fully reflect malaria transmission risks in the big picture (Qi, 2011). To overcome this gap, our research took comprehensive considerations of transmission risks and control capability (Maude et al., 2011). The results of this classification are helpful for decision makers when assessing risks annually and for professionals involved in the NMEP to find out the key factors that may reduce or increase malaria transmission. In this way, appropriate responses can be easily tailored for local settings and may take place in a shorter time (Liu et al., 2012; Zhou et al., 2013).

6.2 Recommendations

Recommendation 1: Based on the marginal cost-benefit principle, more resources should be allocated and invested in the malaria elimination efforts towards the progress of NMEP (Sabot et al., 2010; Tanner and Hommel, 2010). The best strategy for a country is to maintain elimination efforts pertaining to a certain level of human capacity and to consolidate the achievements of malaria elimination while maintaining a certain level of investment (Alonso and Tanner, 2013).

Recommendation 2: Under the aforementioned circumstances, the following five research priorities are recommended in order to fulfil the optimal goal of eliminating malaria nationwide by 2020 (Greenwood, 2008; Hall and Fauci, 2009; Marsh, 2010; Zheng et al., 2013).

1. Improvement of technology to provide more precise predictions with modelling and geographical information systems, in order to set up or promote active surveillance and response systems to prevent the reestablishment of malaria transmission (Bridges et al., 2012; Zhou et al., 2013).
2. Establishment of a resource bank to use as a repository for the *Plasmodium* parasites and their vectors from the whole country, in order to discover the more specific biomarkers to be used in tracing the different species or strain of parasites, and development of more user-friendly, sensitive and rapid diagnostics for malaria case detection (McMorrow et al., 2011).
3. Development of a surveillance approach to monitor artemisinin drug resistance in the migrant population and insecticide resistance, particularly in the southern border areas, in order to contain the spread of artemisinin resistance worldwide (Huang et al., 2012; Li et al., 2000; Liu, 2014).
4. Acceleration of screening and validating of alternative antimalarial drugs, such as the new formulation of artemisinin-based combination therapies, and screening for more candidates of active compounds or molecules to develop new antimalarial drugs (Anthony et al., 2012; Chen, 2014).
5. Development of a G6PD deficiency screening test for a point-of-care diagnostic for primaquine therapy screening in the NMEP (Domingo et al., 2013; Nie and Zhao, 1999).

Recommendation 3: The classification map of malaria transmission in P.R. China at the county level used in our study needs to be updated every 3 years. The gap between achievement of the NMEP and the true trajectory of malaria transmission needs to be investigated every year. The updated information will provide a clear and accurate picture for the decision makers who provide the resources and formulate the intervention strategies for the NMEP, in order to consolidate the achievements and finally achieve the goal of eliminating malaria in P.R. China by 2020 (Bridges et al., 2012; Smith et al., 2013; White et al., 2009).

Recommendation 4: The quality of NMEP activities must be monitored and evaluated frequently in the periods from 2015 to 2020. The indices of monitoring and evaluation are essential for properly maintaining the quality of the NMEP. It is important to formulate standard indices for monitoring before the evaluation. The standard protocol for surveillance and response, either for malaria elimination or for preventing the reintroduction of malaria, are essential at the county level, both in the elimination stage and in the postelimination stage (Cao et al., 2013; Shah, 2010).

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REFERENCES

Alonso, P.L., Tanner, M., 2013. Public health challenges and prospects for malaria control and elimination. Nat. Med. 19, 150–155.

Anthony, M.P., Burrows, J.N., Duparc, S., Moehrle, J.J., Wells, T.N., 2012. The global pipeline of new medicines for the control and elimination of malaria. Malar. J. 11, 316.

Bhaumik, S., 2013. Malaria funds drying up: world malaria report 2012. Natl. Med. J. India 26, 62.

Bi, Y., Hu, W., Liu, H., Xiao, Y., Guo, Y., Chen, S., Zhao, L., Tong, S., 2012. Can slide positivity rates predict malaria transmission? Malar. J. 11, 117.

Bi, Y., Hu, W., Yang, H., Zhou, X.N., Yu, W., Guo, Y., Tong, S., 2013. Spatial patterns of malaria reported deaths in Yunnan province, China. Am. J. Trop. Med. Hyg. 88, 526–535.

Bousema, T., Griffin, J.T., Sauerwein, R.W., Smith, D.L., Churcher, T.S., Takken, W., Ghani, A., Drakeley, C., Gosling, R., 2012. Hitting hotspots: spatial targeting of malaria for control and elimination. PLoS Med. 9, e1001165.

Bridges, D.J., Winters, A.M., Hamer, D.H., 2012. Malaria elimination: surveillance and response. Pathog. Global Health 106, 224–231.

Cao, J., Zhou, S.S., Zhou, H.Y., Yu, Y.B., Tang, L.H., Gao, Q., 2013. Malaria from control to elimination in China: transition of goal, strategy and interventions. Chin. J. Schisto. Control 25, 439–443 (in Chinese).

Chen, C., 2014. Development of antimalarial drugs and their application in China: a historical review. Infect. Dis. Poverty 3, 9.

Chen, W.Q., Su, Y.P., Deng, Y., Zhang, H.W., 2012. Epidemiological analysis of imported malaria in Henan province in 2011. Chin. J. Parasitol. Parasit. Dis. 30, 387–390 (in Chinese).

Kung, C.-C., Hung, S.-C., 1976. Malaria control in China, with special reference ot bioenvironmental methods of control. Chin. Med. J. (Engl). 2, 195–202.

Clements, A.C.A., Reid, H.L., Kelly, G.C., Hay, S.I., 2013. Further shrinking the malaria map: how can geospatial science help to achieve malaria elimination? Lancet Infect. Dis. 13, 709–718.

Cotter, C., Sturrock, H.J., Hsiang, M.S., Liu, J., Phillips, A.A., Hwang, J., Gueye, C.S., Fullman, N., Gosling, R.D., Feachem, R.G., 2013. The changing epidemiology of malaria elimination: new strategies for new challenges. Lancet 382, 900–911.

Cui, L., Yan, G., Sattabongkot, J., Chen, B., Cao, Y., Fan, Q., Parker, D., Sirichaisinthop, J., Su, X.Z., Yang, H., Yang, Z., Wang, B., Zhou, G., 2012. Challenges and prospects for malaria elimination in the Greater Mekong subregion. Acta Trop. 121, 240–245.

Dapeng, L., Leyuan, S., Xili, L., Xiance, Y., 1996. A successful control programme for falciparum malaria in Xinyang, China. Trans. R. Soc. Trop. Med. Hyg. 90, 100–102.

Diouf, G., Kpanyen, P.N., Tokpa, A.F., Nie, S., 2014. Changing landscape of malaria in China: progress and feasibility of malaria elimination. Asia-Pacific J. Public Health 26, 93–100.

Domingo, G.J., Satyagraha, A.W., Anvikar, A., Baird, K., Bancone, G., Bansil, P., Carter, N., Cheng, Q., Culpepper, J., Eziefula, C., Fukuda, M., Green, J., Hwang, J., Lacerda, M., McGray, S., Menard, D., Nosten, F., Nuchprayoon, I., Oo, N.N., Bualombai, P., Pumpradit, W., Qian, K., Recht, J., Roca, A., Satimai, W., Sovannaroth, S., Vestergaard, L.S., Von Seidlein, L., 2013. G6PD testing in support of treatment and elimination of malaria: recommendations for evaluation of G6PD tests. Malar. J. 12, 391.

Dye, C., Mertens, T., Hirnschall, G., Mpanju-Shumbusho, W., Newman, R.D., Raviglione, M.C., Savioli, L., Nakatani, H., 2013. WHO and the future of disease control programmes. Lancet 381, 413–418.

El-Moamly, A., 2013. Malaria elimination: needs assessment and priorities for the future. J. Infect. Dev. Ctries. 7, 769–780.

Feachem, R.G., Phillips, A.A., Targett, G.A., Snow, R.W., 2010. Call to action: priorities for malaria elimination. Lancet 376, 1517–1521.

Fernando, S.D., Navaratne, C.J., Galappaththy, G.N., Abeyasinghe, R.R., Silva, N., Wickermasinghe, R., 2013. The importance of accuracy in diagnosis of positive malaria cases in a country progressing towards malaria elimination. J. Global Infect. Dis. 5, 127–130.

Gao, H.W., Wang, L.P., Liang, S., Liu, Y.X., Tong, S.L., Wang, J.J., Li, Y.P., Wang, X.F., Yang, H., Ma, J.Q., Fang, L.Q., Cao, W.C., 2012. Change in rainfall drives malaria re-emergence in Anhui province, China. PLoS One 7, e43686.

Gmel, G., Rehm, J., Frick, U., 2001. Methodological approaches to conducting pooled cross-sectional time series analysis: the example of the association between all-cause mortality and per capita alcohol consumption for men in 15 European states. Eur. Addict. Res. 7, 128–137.

Greenwood, B.M., 2008. Control to elimination: implications for malaria research. Trends Parasitol. 24, 449–454.

Hall, B.F., Fauci, A.S., 2009. Malaria control, elimination, and eradication: the role of the evolving biomedical research agenda. J. Infect. Dis. 200, 1639–1643.

Ho, C., 1965. Studies on malaria in new China. Chin. Med. J. 84, 491–497.

Ho, C., Feng, L.C., 1958. Studies on malaria in new China. Chin. Med. J. 77, 533–551.

Huang, B.P., Ding, H.H., Zhang, J.Y., Zhao, Y.J., Jin, G., Qian, M.Y., Yang, Z.Y., Zhou, H.X., Wang, J.P., Qian, W.Z., Yang, C.X., 1988. Role of microscopy stations for malaria in malaria control in Jiangsu province. Chin. J. Parasitol. Parasit. Dis. 6, 178–181 (in Chinese).

Huang, F., Tang, L., Yang, H., Zhou, S., Liu, H., Li, J., Guo, S., 2012. Molecular epidemiology of drug resistance markers of *Plasmodium falciparum* in Yunnan province, China. Malar. J. 11, 243.

Jelinek, T., Muhlberger, N., 2005. Surveillance of imported diseases as a window to travel health risks. Infect. Dis. Clin. North Am. 19, 1–13.

Jin, S.G., Jiang, T., Ma, J.Q., 2006. Brief introduction of Chinese infectious disease detection report information system. China Digit. Med. 1, 20–22 (in Chinese).

Kelly, G.C., Tanner, M., Vallely, A., Clements, A., 2012. Malaria elimination: moving forward with spatial decision support systems. Trends Parasitol. 28, 297–304.

Kidson, C., Indaratna, K., 1998. Ecology, economics and political will: the vicissitudes of malaria strategies in Asia. Parassitologia 40, 39–46.

Laurentz, F.K., 1946. Malaria control in China. Tex. State J. Med. 42, 386.

Li, Y., Zhu, Y.M., Jiang, H.J., Pan, J.P., Wu, G.S., Wu, J.M., Shi, Y.L., Yang, J.D., Wu, B.A., 2000. Synthesis and antimalarial activity of artemisinin derivatives containing an amino group. J. Med. Chem. 43, 1635–1640.

Lin, H., Lu, L., Tian, L., Zhou, S., Wu, H., Bi, Y., Ho, S.C., Liu, Q., 2009. Spatial and temporal distribution of falciparum malaria in China. Malar. J. 8, 130.

Liu, C., Qian, H., Tang, L., Zheng, X., Gu, Z., Zhu, W., 1995a. Current malaria stratification in China. Chin. J. Parasitol. Parasit. Dis. 13, 8–12 (in Chinese).
Liu, C.F., Qian, H.L., Tang., L.H., Zheng, X., Gu, Z.C., Zhu, W.D., 1995b. Current malaria stratification in China. Chin. J. Parasitol. Parasit. Dis. 1, 8–12 (in Chinese).
Liu, D.Q., 2014. Surveillance of antimalarial drug resistance in China in the 1980s-1990s. Infect. Dis. Poverty 3, 8.
Liu, J., Yang, B., Cheung, W.K., Yang, G., 2012. Malaria transmission modelling: a network perspective. Infect. Dis. Poverty 1, 11.
Liu, X.Z., Xu, B.L., 2006. Malaria situation and evaluation on the control effect in Henan province during 1990-2005. Chin. J. Parasitol. Parasit. Dis. 24, 226–229 (in Chinese).
Maharaj, R., Morris, N., Seocharan, I., Kruger, P., Moonasar, D., Mabuza, A., Raswiswi, E., Raman, J., 2012. The feasibility of malaria elimination in South Africa. Malar. J. 11, 423.
Marsh, K., 2010. Research priorities for malaria elimination. Lancet 376, 1626–1627.
Maude, R.J., White, N.J., White, L.J., 2011. Feasibility of malaria elimination. Lancet 377, 638.
McMorrow, M.L., Aidoo, M., Kachur, S.P., 2011. Malaria rapid diagnostic tests in elimination settings–can they find the last parasite? Clin. Microbiol. Infect. Dis. 17, 1624–1631.
Mendis, K., Rietveld, A., Warsame, M., Bosman, A., Greenwood, B., Wernsdorfer, W.H., 2009. From malaria control to eradication: the WHO perspective. Trop. Med. Int. Health 14, 802–809.
Ming, G., 2008. Malaria cases among those worked in and returned from Uganda. Chin. J. Parasitol. Parasit. Dis. 26, 240 (in Chinese).
MOH, 2007. Malaria Control Manual. People's Medical Publishing House, Beijing (in Chinese).
Moonasar, D., Morris, N., Kleinschmidt, I., Maharaj, R., Raman, J., Mayet, N.T., Benson, F.G., Durrheim, D.N., Blumberg, L., 2013. What will move malaria control to elimination in South Africa? South Afr. Med. J. 103, 801–806.
Moonen, B., Cohen, J.M., Snow, R.W., Slutsker, L., Drakeley, C., Smith, D.L., Abeyasinghe, R.R., Rodriguez, M.H., Maharaj, R., Tanner, M., Targett, G., 2010. Operational strategies to achieve and maintain malaria elimination. Lancet 376, 1592–1603.
Moore, S.J., Min, X., Hill, N., Jones, C., Zaixing, Z., Cameron, M.M., 2008. Border malaria in China: knowledge and use of personal protection by minority populations and implications for malaria control: a questionnaire-based survey. BMC Public. Health 8, 344.
MOPH, 1990. Advisory committee on parasitic diseases. Malaria situation in China, 1989. Chin. J. Parasitol. Parasit. Dis. 8, 241–244 (in Chinese).
NBSC, 2012. National Bureau of Statistics of China. http://www.stats.gov.cn/english/Statisticaldata/AnnualData/ accessed 13 April 2014.
Nie, C., Zhao, S., 1999. A diagnostic kit to screen individuals with glucose-6-phosphate dehydrogenase defect and its application on anti-malaria spot in the countryside. Chin. Med. J. (Engl.) 112, 349–351.
Pan, J.Y., Zhou, S.S., Zheng, X., Huang, F., Wang, D.Q., Shen, Y.Z., Su, Y.P., Zhou, G.C., Liu, F., Jiang, J.J., 2012. Vector capacity of *Anopheles sinensis* in malaria outbreak areas of central China. Parasit. Vectors 5, 136.
Pindolia, D.K., Garcia, A.J., Wesolowski, A., Smith, D.L., Buckee, C.O., Noor, A.M., Snow, R.W., Tatem, A.J., 2012. Human movement data for malaria control and elimination strategic planning. Malar. J. 11, 205.
Qi, G., 2011. Opportunities and challenges of malaria elimination in China. Chin. J. Schisto. Control 23, 347–349 (in Chinese).
Reibling, N., 2013. The international performance of healthcare systems in population health: capabilities of pooled cross-sectional time series methods. Health Policy 112, 122–132.
Roy, M., Bouma, M.J., Ionides, E.L., Dhiman, R.C., Pascual, M., 2013. The potential elimination of *Plasmodium vivax* malaria by relapse treatment: insights from a transmission model and surveillance data from NW India. PLoS Negl. Trop. Dis. 7, e1979.

Sabot, O., Cohen, J.M., Hsiang, M.S., Kahn, J.G., Basu, S., Tang, L., Zheng, B., Gao, Q., Zou, L., Tatarsky, A., Aboobakar, S., Usas, J., Barrett, S., Cohen, J.L., Jamison, D.T., Feachem, R.G., 2010. Costs and financial feasibility of malaria elimination. Lancet 376, 1604–1615.

Shah, N.K., 2010. Assessing strategy and equity in the elimination of malaria. PLoS Med. 7, e1000312.

Smith, D.L., Cohen, J.M., Chiyaka, C., Johnston, G., Gething, P.W., Gosling, R., Buckee, C.O., Laxminarayan, R., Hay, S.I., Tatem, A.J., 2013. A sticky situation: the unexpected stability of malaria elimination. Philosoph. Trans. R. Soc. Lond. Ser. B, Biol. Sci. 368, 20120145.

Tambo, E., Adedeji, A.A., Huang, F., Chen, J.H., Zhou, S.S., Tang, L.H., 2012. Scaling up impact of malaria control programmes: a tale of events in sub-Saharan Africa and People's Republic of China. Infect. Dis. Poverty 1, 7.

Tang, L., 2000. Progress in malaria control in China. Chin. Med. J. (Engl.) 113, 89–92.

Tang, L.H., Qian, H.L., Xu, S.H., 1991. Malaria and its control in the People's Republic of China. Southeast Asian J. Trop. Med. Public Health 22, 467–476.

Tanner, M., Hommel, M., 2010. Towards malaria elimination–a new thematic series. Malar. J. 9, 24.

Wang, D.Q., Xia, Z.G., Zhou, S.S., Zhou, X.N., Wang, R.B., Zhang, Q.F., 2013. A potential threat to malaria elimination: extensive deltamethrin and DDT resistance to *Anopheles sinensis* from the malaria-endemic areas in China. Malar. J. 12, 164.

Wang, G.Z., Wang, S.Q., Hu, X.M., Meng, F., Li, Y.C., Zeng, W., Cai, H.L., 2012. Analysis of malaria epidemic situation in Hainan province, 2010. Chin. J. Schisto. Control 24, 369–370 (in Chinese).

Wang, L., Wang, Y., Jin, S., Wu, Z., Chin, D.P., Koplan, J.P., Wilson, M.E., 2008. Emergence and control of infectious diseases in China. Lancet 372, 1598–1605.

Wang, L.P., Fang, L.Q., Xu, X., Wang, J.J., Ma, J.Q., Cao, W.C., Jin, S.G., 2009. Study on the determinants regarding malaria epidemics in Anhui province during 2004-26. Chin. J. Epidemiol. 30, 38–41 (in Chinese).

White, L.J., Maude, R.J., Pongtavornpinyo, W., Saralamba, S., Aguas, R., Van Effelterre, T., Day, N.P., White, N.J., 2009. The role of simple mathematical models in malaria elimination strategy design. Malar. J. 8, 212.

W.H.O., Secretariat, 2012. Malaria Policy Advisory Committee to the WHO: conclusions and recommendations of September 2012 meeting. Malar. J. 11, 424.

W.H.O., Secretariat, 2013a. Malaria Policy Advisory Committee to the WHO: conclusions and recommendations of March 2013 meeting. Malar. J. 12, 213.

W.H.O., Secretariat, 2013b. Malaria Policy Advisory Committee to the WHO: conclusions and recommendations of September 2013 meeting. Malar. J. 12, 456.

WHO, 2007. Malaria Elimintation: A Field Manual for Low and Moderate Endemic Countries. WHO Press, Geneva.

Xia, Z.G., Xu, J.F., Zhang, S.S., Wang, R.B., Qian, Y.J., Zhou, S.S., Yang, W.Z., Zhou, X.N., 2014. Determination of key interventions for the transition from control to elimination of malaria in China. Chin. J. Schisto. Control 26, 597–600.

Xia, Z.G., Yang, M.N., Zhou, S.S., 2012. Malaria situation in the People's Republic of China in 2011. Chin. J. Parasitol. Parasit. Dis. 30, 419–422 (in Chinese).

Xiao, D., Long, Y., Wang, S., Wu, K., Xu, D., Li, H., Wang, G., Yan, Y., 2012. Epidemic distribution and variation of *Plasmodium falciparum* and *Plasmodium vivax* malaria in Hainan, China during 1995-2008. Am. J. Trop. Med. Hyg. 87, 646–654.

Xu, B.L., Su, Y.P., Shang, L.Y., Zhang, H.W., 2006. Malaria control in henan province, People's Republic of China. Am. J. Trop. Med. Hyg. 74, 564–567.

Xu, J., Liu, H., 2012. The challenges of malaria elimination in Yunnan Province, People's Republic of China. Southeast Asian J. Trop. Med. Public Health 43, 819–824.

Xu, J.W., Yang, H., Yang, Z.Q., Yang, G.C., Ma, X.W., Wang, W.R., Gu, Y.A., Wang, L.B., Yang, X.W., Ma, J., 2002. Cost-effectiveness analysis of the current measures for malaria prevention in Yuanjiang valley, Yunnan province. Chin. J. Parasitol. Parasit. Dis. 20, 238–241 (in Chinese).

Yan, J., Li, N., Wei, X., Li, P., Zhao, Z., Wang, L., Li, S., Li, X., Wang, Y., Li, S., Yang, Z., Zheng, B., Zhou, G., Yan, G., Cui, L., Cao, Y., Fan, Q., 2013. Performance of two rapid diagnostic tests for malaria diagnosis at the China-Myanmar border area. Malar. J. 12, 73.

Yang, G.J., Gao, Q., Zhou, S.S., Malone, J.B., McCarroll, J.C., Tanner, M., Vounatsou, P., Bergquist, R., Utzinger, J., Zhou, X.N., 2010. Mapping and predicting malaria transmission in the People's Republic of China, using integrated biology-driven and statistical models. Geospat. Health 5, 11–22.

Yang, G.J., Tanner, M., Utzinger, J., Malone, J.B., Bergquist, R., Chan, E.Y., Gao, Q., Zhou, X.N., 2012. Malaria surveillance-response strategies in different transmission zones of the People's Republic of China: preparing for climate change. Malar. J. 11, 426.

Yin, J., Xia, Z., Yan, H., Huang, Y., Lu, L., Geng, Y., Xiao, N., Xu, J., He, P., Zhou, S., 2013a. Verification of clinically diagnosed cases during malaria elimination programme in Guizhou Province of China. Malar. J. 12, 130.

Yin, J.H., Yang, M.N., Zhou, S.S., Wang, Y., Feng, J., Xia, Z.G., 2013b. Changing malaria transmission and implications in China towards National Malaria Elimination Programme between 2010 and 2012. PloS One 8, e74228.

Zhang, H.W., Su, Y.P., Zhao, X.D., Yan, Q.Y., Liu, Y., Chen, J.S., 2010. Imported falciparum malaria situation in Henan province during 2005-2009. Chin. J. Parasitol. Parasit. Dis. 28, 476–477 (in Chinese).

Zhao, X.F., Zhang, J.N., Dong, H.J., Zhang, T., Bian, G.L., Sun, Y.W., Yao, M.H., Chen, K.J., Xu, G.Z., 2013. Epidemiological characteristics of malaria in Ningbo City, China 2000-2011. Trop. Biomed. 30, 267–276.

Zheng, Q., Vanderslott, S., Jiang, B., Xu, L.L., Liu, C.S., Huo, L.L., Duan, L.P., Wu, N.B., Li, S.Z., Xia, Z.G., Wu, W.P., Hu, W., Zhang, H.B., 2013. Research gaps for three main tropical diseases in the People's Republic of China. Infect. Dis. Poverty 2, 15.

Zhou, S.S., Huang, F., Wang, J.J., Zhang, S.S., Su, Y.P., Tang, L.H., 2010. Geographical, meteorological and vectorial factors related to malaria re-emergence in Huang-Huai River of central China. Malar. J. 9, 337.

Zhou, S.S., Wang, Y., Xia, Z.G., 2011. Malaria situation in the People's Republic of China in 2009. Chin. J. Parasitol. Parasit. Dis. 29, 1–3 (in Chinese).

Zhou, S.S., Zhang, S.S., Wang, J.J., Zheng, X., Huang, F., Li, W.D., Xu, X., Zhang, H.W., 2012. Spatial correlation between malaria cases and water-bodies in *Anopheles sinensis* dominated areas of Huang-Huai plain, China. Parasit. Vectors 5, 106.

Zhou, X.N., Bergquist, R., Tanner, M., 2013. Elimination of tropical disease through surveillance and response. Infect. Dis. Poverty 2, 1.

Zhou, X.N., Zhang, S.S., Xu, J.F., Xia, Z.G., Wang, R.B., Qian, Y.J., Zhou, S.S., Yang, W.Z., 2014. Risk assessment of malaria transmission for the national malaria elimination in P.R. China. Chin. J. Parasitol. Parasit. Dis. 32, 414–417 (in Chinese).

Zhou, Z.J., 1981. The malaria situation in the People's Republic of China. Bull. World Health Organ. 59, 931–936.

Zhou, Z.J., 1991. The Studies and Control on Malaria in China. People's Medical Publishing House, Beijing (in Chinese).

Zofou, D., Nyasa, R.B., Nsagha, D.S., Ntie-Kang, F., Meriki, H.D., Assob, J.C., Kuete, V., 2014. Control of malaria and other vector-borne protozoan diseases in the tropics: enduring challenges despite considerable progress and achievements. Infect. Dis. Poverty 3, 1.