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Social and environmental determinants of malaria in space and time in Viet Nam

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ABSTRACT

The malaria burden in Viet Nam has been in decline in recent decades, but localised areas of high transmission remain. We used spatiotemporal analytical tools to determine the social and environmental drivers of malaria risk and to identify residual high-risk areas where control and surveillance resources can be targeted. Counts of reported *Plasmodium falciparum* and *Plasmodium vivax* malaria cases by month (January 2007–December 2008) and by district were assembled. Zero-inflated Poisson regression models were developed in a Bayesian framework. Models had the percentage of the district's population living below the poverty line, percent of the district covered by forest, median elevation, median long-term average precipitation, and minimum temperature included as fixed effects, and terms for temporal trend and residual district-level spatial autocorrelation. Strong temporal and spatial heterogeneity in counts of malaria cases was apparent. Poverty and forest cover were significantly associated with an increased count of malaria cases but the magnitude and direction of associations between climate and malaria varied by socio-ecological zone. There was a declining trend in counts of malaria cases during the study period. After accounting for the social and environmental fixed effects, substantial spatial heterogeneity was still evident. Unmeasured factors which may contribute to this residual variation include malaria control activities, population migration and accessibility to health care. Forest-related activities and factors encompassed by poverty indicators are major drivers of malaria incidence in Viet Nam.

1. Introduction

Following large epidemics in the early 1990s, malaria control in Viet Nam was intensified and over the past 20 years the incidence of malaria in Viet Nam has been greatly reduced (Hung et al., 2002; Barat, 2006). In 2008, 11,355 confirmed cases and 25 deaths were reported, compared with over one million cases and 4500 deaths in 1991 (Ettling, 2002). The decline is probably a consequence of the synergy between a strengthened malaria control program and extensive socio-economic development (Ettling, 2002; Hung et al., 2002; Van Nam et al., 2005). However, malaria remains a problem in some areas, particularly the central highlands, despite control efforts that include enhanced health services, early diagnosis and free treatment with artemisinin derivatives, and free insecticide-treated nets (Ettling, 2002; Van Nam et al., 2005; Thang et al., 2009). The factors believed to have been associated with the persistence of risk in these areas include remoteness and difficulty in delivering and sustaining control efforts; presence in the central highlands of the exophagic and exophilic vector *Anopheles dirus sensu stricto*; poor living and education standards; low perception of risk; and forest-related activities (Erhart et al., 2004, 2005; Sanh et al., 2008; Abe et al., 2009; Morrow et al., 2009; Peeters Grietens et al., 2010). Forest-related activities have been identified as an especially important risk factor for malaria (Guerra et al., 2006), with a population-attributable fraction of 53% estimated in one study in Viet Nam (Erhart et al., 2004). Poverty is also consistently identified as a risk factor for malaria in Viet Nam and reflects the fact that the burden of malaria is greatest in poor ethnic minority communities living in remote areas in close proximity to forests (Erhart et al., 2005; Sanh et al., 2008).

Despite the successes, malaria control remains a high priority for Viet Nam due to the threat of recrudescence or reintroduction into areas where control has been successful and due to evidence of declining efficacy of artemisinin based treatments in parts of

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the Mekong sub-region (Delacollette et al., 2009; Dondorp et al., 2010). Spatial epidemiological tools are increasingly being used to estimate and represent malaria risk, and identify environmental correlates of risk (Brooker et al., 2006; Childs et al., 2006; Noor et al., 2008; Clements et al., 2009; Hay et al., 2009; Reid et al., 2010). At the national level, maps of disease risk can be powerful tools for advocacy and engaging policy makers and funders. At a sub-national level, maps can assist malaria control program managers to mobilise and allocate resources whilst spatial analysis can provide new insights into the determinants of malaria transmission risk and help predict the impact on malaria transmission of new developments, such as infrastructure projects or changes in land use.

We conducted a spatial analysis of the association between counts of malaria cases and indicators of climate, poverty and forest cover. The aim was to identify high-risk areas in Viet Nam where surveillance and control resources can be concentrated. By examining variation explained and unexplained by the aforementioned factors, we also aimed to generate hypotheses regarding additional potential drivers of malaria risk at a time when the overall burden is in decline and the focus of interventions is moving towards active elimination of transmission in localised, high-risk areas.

2. Materials and methods

2.1. Study area

Viet Nam is elongated in a north–south direction and has wide variability in elevation from the coast to the central and northern highland areas (Fig. 1). The country has been divided by the General Statistics Office (GSO; http://www.gso.gov.vn) of Viet Nam into eight socio-ecological zones: Northwest, bordering Lao P.D.R (and with a short border with China); Northeast, a partly mountainous region near the border with China and the Gulf of Tonkin; Red River delta, a densely populated region containing the major cities of Hanoi and Haiphong; North Central Coast, between Lao P.D.R. and the coast; South Central Coast, between the Central Highlands and the coast, and containing the major city of Danang; Central Highlands, a mountainous area bordering Cambodia; Southeast, containing Ho Chi Minh City; and Mekong River Delta in the far south. Each of these zones has a distinct climate by virtue of its latitude and topography. The first administrative division of Viet Nam is the province (n = 64) and these are sub-divided into districts (n = 670).

2.2. Malaria data

The numbers of reported cases of *Plasmodium falciparum* and *Plasmodium vivax* malaria by month from January 2007–December 2008, and by district, were provided by the National Institute of Malariology, Parasitology and Entomology (NIMPE), Viet Nam. In Viet Nam, malaria diagnosis is mostly based on microscopy but sometimes it was done by rapid diagnostic test (RDT). Data on the number of cases were missing in some districts for some months, for each type of malaria. The number of missing observations was 531 out of a total of 16,080 district/months (3.3%). These missing values were imputed by averaging the values from the two adjacent months in which data were collected; in most cases, these numbers were zero.

2.3. Demographic, social and environmental data

Population data by district were available from the GSO for 2006 and 2007. The district populations were imputed by month as follows: the difference in the district population in 2006 and 2007 was calculated and divided by 12 to give a monthly population increase (I). The 2007 population was assumed to apply to January 2007 and for subsequent months $i = (1,2,\ldots 23)$, the population (P) in district j was calculated as follows: $P_{ij} = P_{i-1,j} + I_j$.

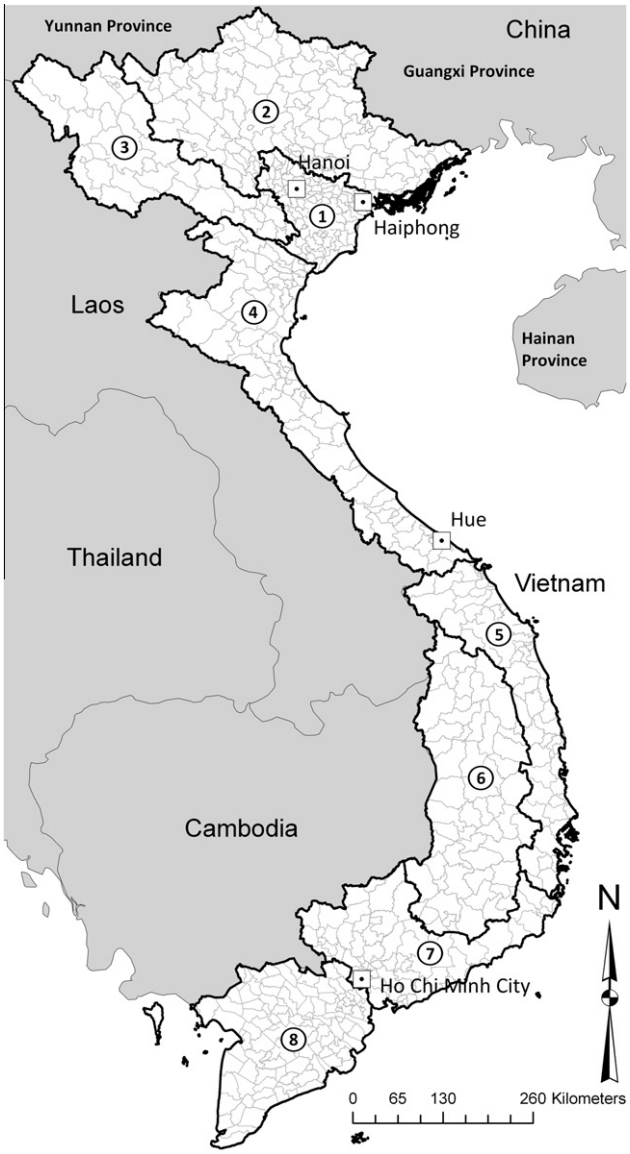

Fig. 1. Location of Viet Nam, showing the eight socio-ecological zones recognised by the General Statistics Office: (1) Red River Delta; (2) Northeast; (3) Northwest; (4) North Central Coast; (5) South Central Coast; (6) Central Highlands; (7) Southeast; and (8) Mekong River Delta.

Temperature and precipitation data were obtained from the WORLDCLIM project (http://www.worldclim.org/). These are long-term average values collected at weather stations, interpolated using geostatistics to a 1 km^2 global grid. Digital elevation data were obtained from the Shuttle Radar Topography Mission (SRTM; http://www2.jpl.nasa.gov/srtm/) of the US National Geospatial-Intelligence Agency and the US National Aeronautics and Space Administration (Farr et al., 2007). These data were sampled at 3 arc-s (approximately 90 m). Data on forest cover from 2005 were obtained from the Ministry of Agriculture and Rural Development (MARD), Viet Nam. MARD updates land cover maps every 5 years based on LandSat and other remote sensing data, which are then ground-truthed by MARD staff. The original MARD map consisted of 17 different land cover categories that were collapsed into forest and non-forest categories. Each of these environmental variables, available electronically in raster (i.e. grid) format, was imported into