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Climate patterns and mosquito-borne disease outbreaks in South and Southeast Asia

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ABSTRACT

Background: Vector-borne infectious diseases, particularly mosquito-borne, pose a substantial threat to populations throughout South and Southeast Asia. Outbreaks have affected this region several times during the early years of the 21st century, notably through outbreaks of Chikungunya and Dengue. These diseases are believed to be highly prevalent at endemic levels in the region as well. With a changing global climate, the impacts of changes in ambient temperatures and precipitation levels on mosquito populations are important for understanding the effects on risk of mosquito-borne disease outbreaks. This study aims to make use of a large data set to determine how risk of mosquito-borne infectious disease outbreaks relates to the highest monthly average temperature and precipitation for each year in South and Southeast Asia.

Methods: Generalized additive models were used in a marked point process to fit nonlinear trends relating temperature and precipitation to outbreak risk, fitting splines for temperature and precipitation. Confounding factors for nation affluence, climate type, and ability to report outbreaks were also included.

Results: Parabolic trends for both temperature and precipitation were observed relating to outbreak risk. The trend for temperature, which was significant, showed that outbreak risk peaks near 33.5 °C as the highest monthly average temperature. Though not significant, a trend for precipitation was observed showing risk peaking when the highest monthly average precipitation is 650 mm.

Conclusions: Peak levels of temperature and precipitation were identified for outbreak risk. These findings support the notion of a poleward shift in the distribution of mosquitoes within this region rather than a poleward expansion in geographic range.

Introduction

Vector-borne infectious diseases infect over a billion people each year, contributing to over a million deaths globally [1]. Developing nations and low socioeconomic status groups are particularly vulnerable [1]. Recent resurgences in vector-borne diseases and concerns of global climate change have together prompted questions regarding their potential relationship [1,2]. The pathogens and parasites that cause these diseases as well as the insect vectors that transmit them exhibit sensitivity to levels of temperature and precipitation; these relationships are likely to be confounded by socioeconomic and geographic factors [3].

Among vector-borne outbreaks, mosquito-borne outbreaks occur with the highest frequency [4]. Common diseases transmitted by the *Aedes* or *Anopheles* genera include Chikungunya, malaria, and dengue [1–4]. As a result, infectious diseases transmitted by mosquitoes are of particular interest to researchers. Mosquitoes are known to breed in warm, wet regions, motivating interest in investigating their sensitivity to temperature and precipitation patterns.

Previous work has found that higher temperatures are associated with outbreaks, but the complex dynamics between the environment, vectors, and disease transmission warrant careful research [5–8]. In particular, ranges in temperature and extreme temperature effects may affect the ability of mosquitoes to effectively transmit disease pathogens [3]. Diurnal temperature ranges have been found to be more important than average temperatures when examining the development and transmission of malaria

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parasites [9–11]. These findings indicate that patterns in climate besides average levels should be used to properly investigate the impact of climate change on mosquito-borne diseases. Similarly, extreme levels of precipitation have been indicated to be more useful than average precipitation. Events such as flooding or the drying of riverbeds has been demonstrated to bear a greater impact on the life cycles of the vectors and the incubation of the parasites [12]. Due to the various mechanisms by which climate and outbreak risk can interact, nonlinear trends are likely to exist [5,7]. These notions lead to interest in how maxima may relate to disease outbreaks.

The continent of Asia has been identified as a particularly vulnerable region for mosquito-borne infectious diseases, particularly South and Southeast Asia [13]. In addition to its high vulnerability to mosquito-borne outbreaks, this region exhibits heterogeneity in socioeconomic factors that may confound this relationship as well as similarities in baseline climate [14–16].

Nations in South and Southeast Asia have experienced large outbreaks of mosquito-borne infectious diseases, commonly Chikungunya and dengue. Laos experienced large outbreaks of dengue in 2010 and 2013 [17]. Thailand experienced high incidences of dengue in 2001, 2002, and 2010. During these three years, the incidence was 50 percent higher than the average throughout the ten-year period [18]. Between 2000 and 2001, Laos experienced over 800,000 cases of dengue [18]. Chikungunya outbreaks were observed in India between 2005 and 2008, Sri Lanka in 2006, Malaysia in 2006 and 2008 [19], and Thailand between 2008 and 2009 [19,20]. Nearly all adults over the age of 45 in Thailand are seropositive for dengue, and approximately half are seropositive for Chikungunya [21]. Furthermore, Zika virus has been detected in humans in Cambodia in 2010 and in the Philippines in 2012, and in Indonesia in 2014 [22].

This study aims to investigate the relationships between maximum monthly temperature and precipitation and risk of mosquito-borne infectious disease outbreaks in South and Southeast Asia. Previous work has isolated specific diseases and small regions, without combining data for multiple diseases transmitted by an entire taxonomic family of vectors [5–12]. Combining multiple diseases would require the use of a comprehensive data source that provides adequate outbreak information. In the absence of a large database, past work has focused on data from prevalence estimates or textual records of first occurrence of pathogen emergence [14,23]. Such studies have suggested considering nonlinear trends [5,7], shown that increases in temperature are associated with increased risk of mosquito-borne diseases [6,8], and indicated that average temperatures are not ideal indicators [9–11].

This study attempts to combat this lack of big data solutions by using a large global database of infectious disease outbreaks. This database consists of records between 1980 and 2013, documenting over 12,000 outbreaks globally [4,14]. The data, combined with climate data for temperature and precipitation, were used in concert with covariates believed to confound the relationship between the climate variables and disease outbreak risk. The findings of this study not only add to the existing literature relating temperature and precipitation levels to risk of mosquito-borne diseases, but also demonstrate the use of large data sets to aggregate outbreak data by a common vector in a broader region.

Methods and materials

Outbreak data

The Global Infectious Disease and Epidemiology Online Network (GIDEON) compiles published reports of infectious disease outbreaks, recording information such as disease, transmission vector, country, year, and number of cases. GIDEON defines outbreaks when they are specified as such in source literature, when observed as a cluster or grouping of cases, or if citations of animal disease are specified [4]. The textual records of outbreaks were previously transformed with a bioinformatics pipeline into an accessible, published database containing records of outbreaks between 1980 and 2013 [14]. Mosquito-borne disease outbreak records occurring in South and Southeast Asia were selected for analysis. The nations included were: Bangladesh, Cambodia, India, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Thailand, and Vietnam. Fig. 1 displays the region of analysis as well as locations of all mosquito-borne outbreaks observed.

Each mosquito-borne disease outbreak record was manually reviewed and its specific location, i.e. city or town of a reported outbreak, was captured if reported. Latitude and longitude coordinate pairs were assigned to the outbreaks, representing the centroids of the reported outbreak locations.

Climate data

The University of East Anglia Climatic Research Unit (CRU) has compiled monthly climate data, including average temperature in degrees Celsius and precipitation in millimeters, from over 4000 weather stations worldwide [24]. Data were compiled into geographic grids of $0.5 \times 0.5^{\circ}$ of latitude and longitude. Cleaned data were available between 1970 and 2009. These grids provided the units for analysis.

Disease outbreaks were assigned to the grids containing the reported outbreak coordinates. Only CRU geographic grids associated with at least one disease outbreak between 1980 and 2009 were included in the analysis to ensure that grids where outbreaks cannot occur, including uninhabited regions, were excluded from analysis.

To conform to the yearly outbreak data, the monthly CRU data were transformed to yearly measurements by using the maximum of the 12 monthly averages to represent the maximum monthly average for each year. These maximum monthly averages were created for both temperature and precipitation. Each year is represented by the month with the highest mean temperature and with the highest mean precipitation.

Country-level covariates

World Bank and Freedom House data were used to obtain country-level covariates that potentially confound the effect of climate on outbreak risk. These confounders may represent dynamics of mosquito-borne disease transmission or outbreak reporting. They are: population density (persons per square kilometer), gross domestic product (2013 US dollars), and press freedom (free, partially free, not free) [14–16,25]. Historical data were collected for the years 1980 through 2009.

Missing values for these covariates were singly imputed for all world nations using a Bayesian implementation of cubic B-splines. Worldwide nations were grouped based on geographic location and groupings in publications from the World Bank [16] and United Nations [26]. Within each group, Bayesian spline models were fit to impute missing values based on trends in nations with similar socioeconomic statuses. Details of the imputation can be found in the Supplementary materials. Imputation was desired rather than finding alternate data sources in order to maintain consistency of data sources.

Bands of latitude

Another potential source of confounding was the variability in typical climates found throughout the study region. Not all points in analysis are within the tropics, leading to differences in sea-