Climate Suitable Conditions Index and Autochthonous Dengue Infections: an Early Warning Index

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Abstract

Background: *Aedes aegypti* is the primary vector of dengue and contributes to most major epidemics of this virus worldwide. *Aedes albopictus* is also blamed for certain epidemics, as the 2014 Guangdong dengue outbreak. In Guangdong province, *Ae. albopictus* is thought to be the dominant vector species, with *Ae. aegypti* absent from most areas. Whether or not primary mosquito vectors are present, optimal climatic conditions for dengue vector species may play a substantial role in epidemics of the virus. We hypothesise that although vector species are required to initiate and establish an outbreak, favourable weather conditions may then grow and perpetuate the outbreak via complex effects on vector sympatry or interactions.

Methods: Vector species-specific suitable conditions index (SCI) and autochthonous dengue case data were fitted to negative binomial (NB) regression models. After accounting for potential confounders, we assessed the relationship between SCI and autochthonous dengue cases. We assumed SCI interaction was a proxy for vector species sympatry and SCI difference a proxy for interspecies competition. Finally, we explored the relationship between these assumed conditions and the autochthonous dengue case.

Results: Autochthonous dengue cases are associated negatively with SCI for *Ae. albopictus* and positively with SCI for *Ae. aegypti*. According to the NB regression models, autochthonous dengue cases increased 4% (Incident Rate Ratio (IRR): 1.04, 95% CI: 1.02, 1.06) for every unit increase in SCI for *Ae. aegypti*, but decreased by 3% (IRR: 0.97, 95% CI: 0.96, 0.99) for *Ae. albopictus* SCI. There was also an interaction between two SCIs and a positive effect of the difference in SCIs on autochthonous dengue cases. These findings support the hypothesis that vector sympatry and interactions may influence the risk of a dengue outbreak.

Conclusions: Our results confirm the hypothesis that the dengue virus is more transmissible in regions with warmer weather conditions (high SCI for *Ae. aegypti*). SCI of *Ae. aegypti* would be a valuable index to predict dengue transmission even in the absence of *Ae. aegypti* but with *Ae. albopictus* present. The results also support that the SCI is beneficial for evaluating dengue outbreak risk in terms of vector sympatry and interactions in the absence of entomology data in future research.

Background

Dengue has risen rapidly throughout the world in recent decades. According to model estimates, 390 million dengue virus infections occur yearly [1], and 3.9 billion people are at risk of infection [2]. Dengue cases reported to World Health Organization (WHO) have climbed from 505,430 in 2000 to over 2.4 million in 2010 and 5.2 million in 2019 [3]. To date, dengue is the most prevalent human arboviral infection worldwide. Dengue is an arthropod-borne virus (arbovirus) infection caused by four virus serotypes, transmitted by the two *Aedes* mosquito species: *Ae. aegypti* and *Ae. albopictus* [4]. *Ae. aegypti* and *Ae. albopictus*, once zoophilic forest species from sub-Saharan Africa and Asia respectively, are now widespread globally due to rapid human population growth and international trade in the last century and climate change more recently [5, 6].

Ae. aegypti is considered highly urban-adapted, while *Ae. albopictus* can thrive in peridomestic and rural environments over a wide range of tropical, subtropical and temperate climates [7]. In China, *Ae. aegypti* was once only present in the areas of the tropical zone below 22°N, such as Hainan Island, Leizhou peninsula in Guangdong province and coastal area in Beibu Gulf of Guangxi province. However, since the 2000s, *Ae. aegypti* has also been found in some bordering counties in Yunnan province, located between 22°N and 25°N [8]. In contrast, *Ae. albopictus* has a wide distribution in both tropical and temperate regions of China from 41°N to the country's southern reaches [9]. Based on historical climatic data from the last decade, most areas where *Ae. albopictus* became established had an annual mean temperature above 11°C and annual mean precipitation above 500mm [10].

Ae. aegypti is considered the principal dengue vector and has contributed to a global resurgence of dengue epidemics in the past three decades. All major epidemics of dengue have occurred only in areas where *Ae. aegypti* was found [11]. Conversely, *Ae. albopictus* is considered to play a relatively minor role in dengue virus transmission compared to *Ae. aegypti*, and is not considered an 'efficient' epidemic vector [11, 12]. In China, dengue outbreaks in Hainan province in 1980 and 1985-86 and Xishuangbanna of Yunnan province in 2013 were typically attributed to *Ae. aegypti* [13, 14]. However, outbreaks, largely of classical dengue (i.e., few cases of severe disease) in Guangdong, Fujian, and Zhejiang province between 2004 and 2010, were

caused solely by *Ae. albopictus* in the absence of *Ae. aegypti* [15, 16]. In 2014, China's largest dengue outbreak to date (or at least since dengue became a notifiable disease in 1989) occurred in Guangdong, where *Ae. albopictus* appears to be the sole dengue vector [17].

The dynamics of dengue transmission and outbreak are complicated, including hosts (humans), pathogens and mosquito vectors with their ecological interactions. The WHO recommends that many dengue-endemic nations use vector surveillance to provide a quantitative evaluation of dengue vector population fluctuations in the number and geographical distribution to forecast outbreaks and assess management options [18]. However, dengue transmission usually depends on a range of factors, including serostatus of the human host population, mosquito density and climate, rather than at a fixed entomologic threshold [19]. Additionally, there has been minimal evidence of meaningful correlations between vector biomass indices and dengue transmission, which might be used to forecast epidemics consistently [20]. Furthermore, the geographical variability in the association between dengue vector abundance and transmission or outbreak occurrence is poorly understood, suggesting that locality-specific vector population indices may be critical in forecasting dengue transmission increases [21], and other data may have better potential as predictors.

Climate is a crucial environmental determinant of vector geographical distribution and vectorial capacity. Climate factors such as temperature and precipitation and their seasonal patterns can fundamentally affect mosquito population dynamics and individual features relevant to vector biologies like development, reproduction and survival, and consequently dengue virus transmission patterns [22–24]. A sufficiently warm ambient temperature is also critical for virus replication and dissemination to the salivary glands in female mosquitoes. Conversely, cooler temperatures slow this viral amplification, and if the development time of the pathogen exceeds the life span of the infected mosquito, transmission cannot occur [7, 25]. Previous studies have estimated suitable temperatures that support dengue transmission [26–29]. Mordecai et al. have synthesised the existing empirical evidence on temperature suitability for vector and pathogen survival and used a mechanistic approach to ascertain suitable temperatures for vector capacity in dengue transmission [30]. Based on these identified suitable temperature ranges for dengue vectorial capacity, we have previously developed the Suitable Conditions Index (SCI) for *Ae. aegypti* and *Ae. albopictus* to define their potential vector capacity. SCI ranks geographic locations based on their climatic suitability for each vector species that transmits dengue and theoretically defines the spatial parameters for transmission [31]. By incorporating SCI into an outbreak epidemiologic study, it is possible to investigate the potential value of SCI data for dengue transmission or outbreak prediction. Here, we use the case of the Guangdong dengue outbreak in 2014 to assess the potential of a climate-based SCI as a local dengue outbreak early warning index.

Methods

Study area

Guangdong (at 109°39'53" E to 117°18'51" E and 20°13'24" N to 25°31'10") province is in southern China, with approximately 179,800 km² in area. Guangdong is the most populous province in China, with 126.01million inhabitants (7th National Population Census), accounting for 8.93% of Mainland China's population [32]. Guangdong has a humid subtropical climate; winters are short, mild, and relatively dry, while summers are long, hot, very wet and influenced by the Asian monsoon season [33].

Data collection

Data on locally acquired and imported dengue cases reported from Guangdong in 2014 were collected from the National Notifiable Infectious Diseases Reporting Information System. Dengue has been a statutorily notifiable communicable disease in China since 1989 [34]. Dengue is diagnosed according to the national surveillance protocol with standardised case definitions, including clinically diagnosed and laboratory-confirmed dengue cases. An imported case was defined as one for which the patient had travelled abroad to a dengue-endemic country within 15 days of the onset of illness. In some cases, importation was defined based on laboratory results showing that the infection dengue virus had a sequence similarity in the premembrane (prM) and envelop (E) glycoproteins as (prM-E) region of the virus genome compared with viruses isolated from the putative source region where the patient had travelled [35]. In the absence of meeting the criteria for an imported case, a dengue case was considered an autochthonous dengue case.

SCI has been developed in our previous research [31] to define climate suitability for each species of *Ae. aegypti* and *Ae. albopictus*. Based on the optimal temperature range for vectorial capacity in the transmission identified by Mordecai et al. using robust mechanistic models [30], the SCI was defined as the product of the number of suitable months (where the monthly minimum and maximum temperature is within the determined temperature range) and the average monthly precipitation (as a weight). The input data for the SCI model were available on an annual interval and at the county scale. Therefore, we produced SCI values for each species of *Ae. aegypti* and *Ae. albopictus* in 2014 for 124 counties/districts in Guangdong.

Normalised Difference Vegetation Index (NDVI) data were extracted from NASA’s Moderate Resolution Imaging Spectroradiometer (MODIS) website (MODIS Web (nasa.gov)). NDVI data are used to characterise and monitor the global distribution of vegetation conditions and are often used to model global and regional climate [36]. We utilised MODIS Vegetation Indices (MOD13A3 product) version 6 data provided monthly at the 1-kilometre spatial resolution, then aggregated annually and at the county scale [37]. In addition, human population data were obtained from the Sixth National Population Census data (2010), which is available from the National Bureau of Statistics of China (<http://www.stats.gov.cn/enGLiSH/>).

Negative binomial regression (NB) models

We fitted a fixed-effects NB model to assess the relationship between autochthonous dengue cases and potential predictors, including SCI for each vector species, NDVI, human population density, and the number of imported dengue cases. An NB model was used to account for the over-dispersed count of the dengue case (Table 1). A log-scale population was used as an offset to control for variation in human population size. Univariable and multivariable analyses were implemented successively. In univariable analyses, we consider each potential predictor in an NB regression model to identify significant predictors. In a multivariable analysis, we examined the potential effect of significant predictors on dengue case occurrence (presented as incident rate ratio, IRR). Model goodness of fit was assessed by Bayesian information criterion (BIC), where smaller values of BIC indicate a better fit.

Table 1
Summary statistics for autochthonous dengue cases, imported dengue cases, Normalized Difference Vegetation Index (NDVI), human population density, SCI for *Ae. aegypti* and SCI for *Ae. albopictus* in 124 counties/districts of Guangdong, 2014

Variable	Mean	SD	Median	Minimum	Maximum
Autochthonous dengue	361.79	1387.31	10.50	0	11837
Imported dengue	0.62	2.08	0	0	15
NDVI	185.40	28.42	193.22	94.78	255.00
Population density	2131.33	4008.42	502.35	76.91	21686.58
SCI- <i>Ae. aegypti</i>	102.48	22.84	103.79	45.42	154.70
SCI- <i>Ae. albopictus</i>	71.79	20.69	63.60	34.92	138.68
SD: Standard deviation SCI: Suitable Conditions Index NDVI: Normalized Difference Vegetation Index					

We also examined the potential interaction between SCI for *Ae. albopictus* and SCI for *Ae. aegypti* (SCI-*Ae.aegypti* × SCI-*Ae. albopictus*). We assumed the SCI was a proxy for vector density; a high level of SCI represented high vector density and vice versa. The interaction between the two vectors was examined by assessing how the effect of the SCI of a specific vector on autochthonous dengue case occurrence changed when the SCI of another vector changed. The SCI difference (defined as SCI-*Ae.aegypti*-SCI-*Ae. albopictus*) was also fitted to the NB model. As *Ae. albopictus* has a different niche to *Ae. aegypti* in terms of feeding preferences and, critically for the SCI, thermal range, it was reasonable to assume that more considerable difference may indicate a reduced probability of ecological constraints between the two mosquito species. We use the SCI difference to explore the correlation between the probability of ecological constraints and dengue transmission risk. The regression analysis was implemented in Stata/SE 16.0 (StataCorp, TX, USA) using “xtnbreg” (Fixed-effects, random-effects, & population-averaged negative binomial models) [38].

Results

Descriptive analyses

Summary statistics for autochthonous dengue cases, imported cases, NDVI, human population density, SCI for *Ae. aegypti* and SCI for *Ae. albopictus* are presented in Table 1. In 2014, there were 44,939 (44,862 autochthonous and 77 imported) dengue cases recorded from 107 out of 124 counties in Guangdong, number of cases per county/district ranged from 0 to 11,846 (mean number of cases per county/district: 362.41, standard deviation: 1,388.57). The mean annual dengue incidence averaged 28.9 cases per 100,000 population, with the highest incidence (532.6/100,000) being reported from Baiyun District, followed by Liwan (497.3/100,000), Yuexiu (414.1/100,000), and Haizhu District (385.2/100,000), all of which are located in Guangzhou, the capital city of Guangdong (Fig. 1a).

Guangdong has the most suitable climatic conditions for dengue transmission for each vector (Fig. 1b, c). SCI for *Ae. aegypti* was highest in the Leizhou peninsula below 22°N and western coastal areas between 22-23°N, with gradually reducing suitability moving further north, and the lowest was observed in the furthest northern part (Fig. 1b). SCI for *Ae. albopictus* was less likely to be distributed evenly through low to high latitude (Fig. 1c). Regions with the highest SCI for both vectors overlapped and located in the western coastal areas below 23°N (Fig. 1b,c).

The relationship between autochthonous dengue incidence, latitude, imported case and SCI for the two vector species is presented in Fig. 2. The correlation pattern between autochthonous dengue case and latitude was consistent between the two vector species; incidence and SCI were high in 23°N (Fig. 2a and b). The relationship between imported dengue cases, vectors and autochthonous dengue cases indicated a strong relationship between autochthonous and imported dengue cases, which may remain independent over various levels of SCI for each vector species (Fig. 2c and d).

The relationship between autochthonous dengue incidence and SCI for *Ae. aegypti* was examined when SCI for *Ae. albopictus* was held constant at four levels from low to high (34.9 to 58.1, 58.2 to 63.6, 63.8 to 84.5 and 85.5 to 141.8), with results presented in Fig. 2e. There was a moderate relationship between dengue incidence and SCI for *Ae. aegypti* when SCI of *Ae. albopictus* was held constant at 34.9 to 58.1 (e.g., minimum to mean – one SD) (Fig. 2e).

Spearman correlation

Spearman correlation coefficients between any two variables considered in this study are presented in Table 2. There was a moderate relationship between autochthonous dengue incidence and SCI for *Ae. aegypti* ($r_s = 0.41$, $p=0.000$), while there was a weak correlation between incidence and SCI for *Ae. albopictus* ($r_s = -0.18$, $p=0.000$). There was a moderate correlation between dengue incidence and difference in SCI ($r_s = 0.53$, $p=0.000$). There was a moderate correlation between autochthonous dengue incidence and the other variables, including imported cases, NDVI and human population density. There was a moderate relationship between the two SCIs ($r_s = 0.43$, $p=0.000$).

Table 2
Correlation between autochthonous dengue annual incidence and exploratory variables

	Autochthonous dengue	Sci-Ae.aegypti	Sci-Ae.albopictus	Imported dengue	NDVI	Population density	Difference in SCI
Autochthonous dengue	1.00						
Sci-Ae.aegypti	0.41 (0.000)	1.00					
Sci-Ae.albopictus	-0.18 (0.049)	0.43 (0.000)	1.00				
Imported dengue	0.50 (0.000)	0.18 (0.048)	-0.20 (0.024)	1.00			
NDVI	-0.56 (0.000)	-0.24 (0.007)	0.34 (0.000)	-0.42 (0.000)	1.00		
Population density	0.64 (0.0000)	0.34 (0.000)	-0.18 (0.044)	0.53 (0.000)	-0.73 (0.000)	1.00	
Difference in SCI	0.53 (0.000)	0.53 (0.00)	-0.46 (0.000)	0.32 (0.000)	-0.51 (0.00)	0.46 (0.000)	1.00
Cell contents: Spearman's rho (r_s) (p -value)							

NB Regression models

Results of univariable analyses (Model I in Table 3) indicated that SCI for *Ae. aegypti*, the difference between SCI for *Ae. aegypti* and SCI for *Ae. albopictus* (Difference in SCI), NDVI, and imported case were significant predictors of dengue transmission. Results of multivariable models without the interact terms (Model II and III) indicated that autochthonous dengue cases increased 4% (IRR: 1.04, 95% CI: 1.02, 1.06) for one unit increase in SCI for *Ae. aegypti*, but decreased by 3% (IRR: 0.97, 95% CI: 0.96, 0.99) for every unit increase in SCI for *Ae. albopictus*. Autochthonous dengue cases increased 28% (IRR: 1.28, 95% CI: 1.02, 1.60) and 4% (IRR: 1.04, 95% CI: 1.02, 1.06) for one unit increase in imported case and difference in SCI, respectively. Dengue case decreased 3% (IRR: 0.97, 95% CI: 0.96, 0.99) for one unit increase in NDVI. A significant interaction effect between SCI of *Ae. albopictus* and SCI of *Ae. aegypti* was found, where SCI of *Ae. albopictus* significantly reduced the effect SCI of *Ae. aegypti* on autochthonous dengue cases (Table 3 Model IV). To avoid possible collinearity between NDVI and population density ($r_s = -0.73$, $p = 0.000$, Table 2), more importantly, the population density was not a significant predictor in multivariable models, the population density was excluded from NB regression analyses.

Table 3
Incident rate ratio (IRR) and 95% confidence interval (CI) for potential predictors of autochthonous dengue case in Guangdong, 2014

Variable	Model I ^a	Model II ^b	Model III ^c	Model IV ^d
	IRR (95% CI)	IRR (95% CI)	IRR (95% CI)	IRR (95% CI)
SCI- <i>Ae. aegypti</i>	1.03 (1.02, 1.05)	1.04 (1.02, 1.06)	-	1.06 (1.03, 1.09)
SCI- <i>Ae. albopictus</i>	0.99 (0.97, 1.01)	0.97 (0.95, 0.99)	-	-
Difference in SCI	1.05 (1.04, 1.07)	-	1.04 (1.02, 1.06)	-
NDVI	0.95 (0.94, 0.97)	0.98 (0.96, 0.99)	0.98 (0.96, 0.99)	0.97 (0.96, 0.99)
Imported case	1.59 (1.31, 1.93)	1.28 (1.02, 1.61)	1.28 (1.02, 1.60)	1.28 (1.01, 1.61)
SCI- <i>Ae.aegypti</i> × SCI- <i>Ae. albopictus</i>	-	-	-	0.99 (0.99, 0.99) ^e
BIC		1165.30	1162.67	1165.91
^a Univariable models				
^b Multivariable models with predictors being SCI- <i>Ae aegypti</i> , NDVI, Imported case				
^c Multivariable models with predictors being Difference in SCI, NDVI, Imported case				
^d Multivariable model III with interact term SCI- <i>Ae.aegypti</i> × SCI- <i>Ae. albopictus</i>				
^e 0.9998 (0.9996, 0.9999), <i>p</i> =0.001				
SCI: Suitable condition index				
NDVI: Normalized Difference Vegetation Index				
BIC: Bayesian information criterion				

Discussion

We investigated the association between SCI and autochthonous dengue cases in this study and the value of SCI as a predictor of dengue outbreak risk. We found SCI was associated with autochthonous dengue cases, implying SCI might be beneficial in forecasting the probability of local dengue transmission or outbreak occurrence. We also discovered a statistically significant interaction between SCI for *Ae. albopictus* and SCI for *Ae. aegypti*, which invites the hypothesis that vector species interactions may also influence dengue virus transmission.

We found opposing relationships between species-specific SCI and autochthonous dengue occurrence in Guangdong: SCI for *Ae. aegypti* was positively associated with disease cases while SCI for *Ae. albopictus* was negatively related to local cases. This finding is not surprising because there are still several significant gaps in understanding correlations between climate suitability and virus transmission probability and intensity. Although temperature-dependent transmission models prove valuable for predicting vector spread and dengue transmission, most of these modelling studies find a very broad correlation of transmission occurring within a temperature range [22, 39]. Few can sufficiently capture transmission dynamics to provide reliable predictions. Human mobility and behaviour, urban development and microclimates, aquatic habitat supply, vector control techniques may all impact dengue transmission [23, 40–45]. These characteristics may be as important as climate suitability in determining dengue transmission risk. Moreover, transmission dynamics and bionomic responses differ across vector species, mosquito populations and dengue virus serotypes [20, 46, 47]. While some potential confounders have been adjusted in our study, other elements may contribute to dengue transmission that we have not considered. Finally, whether primary mosquito vectors are present, optimal climatic conditions for dengue vector species may play a substantial role in the outbreak. This suggests the possibility that vector

species are a prerequisite for initiating and establishing a dengue outbreak; suitable conditions may expand and maintain the outbreak through complicated effects on vector sympatry or interactions.

Although SCI was not equivalent to mosquito species absence/presence or densities revealed only by entomological surveillance data, specific vector mosquitoes should only occur at a suitable habitat with favourable meteorological conditions. Our findings indicate the possibility that SCI might be indirectly associated with autochthonous dengue cases through the variation in dengue vector population, which means that SCI might be beneficial in dengue transmission or outbreaks prediction in the absence of entomological data. This might be meaningful in some dengue-endemic countries where vector absence/presence or density data are usually unavailable and, more importantly, there has been no reliable indication of any consistent association between entomological indices and dengue cases [20].

Our results suggested a significant interaction between SCI for *Ae. aegypti* (main effect) and SCI for *Ae. albopictus*, which means the expected effect of SCI for *Ae. aegypti* on autochthonic dengue cases may change over the various levels of SCI for *Ae. albopictus*. Specifically, a one-unit increase in SCI for *Ae. aegypti* may indicate a higher risk of dengue in a region with a low SCI of *Ae. albopictus* than in a region with a high SCI of *Ae. albopictus*. Given that regions with high SCI for each *Aedes* vector have some overlaps in Guangdong, the coexistence of these two vectors is theoretically possible. In areas sympatric for the two species, declining population and displacement of *Ae. aegypti* have been reported as a result of *Ae. albopictus* superiority in resource competition at the larval stage and asymmetric sterilisation at the adult stage following interspecific mating [48]. It has also been supposed that *Ae. aegypti* prefers to reproduce in areas devoid of *Ae. albopictus* [49]. Although there is no evidence of vector competitiveness from a field study in Guangdong, recent evidence from a laboratory experiment suggests competitive displacement is theoretically possible. Larvae of the two species were mixed, allowed to emerge and then cycled through six generations, with the results that *Ae. aegypti* from the Leizhou peninsula were suppressed (a combination of generation time and abundance was used to judge competitiveness) by *Ae. albopictus* from Guangzhou but not by *Ae. albopictus* from other cities [50]. This finding warrants further exploration because the sympatric habit for the two species is expected to expand to additional areas in China [51].

We also observed that the difference in SCI was positively associated with dengue transmission. The two *Aedes* species are usually distinct in terms of ecological environment, feeding preferences and, critically for the SCI, thermal range. Therefore, high SCI for *Ae. aegypti* correlating with low SCI for *Ae. albopictus* is meaningful, indicating that a larger difference in SCI may indicate less competition between the two mosquito species. In other words, areas that are optimally suitable for both species (i.e. low difference in SCI) may, somewhat counterintuitively, produce a decreased dengue transmission risk potentially through the competitive displacement of one species by the other.

There are several limitations to our study. SCI is estimated using annual data and may not accurately capture seasonal variation and time-lag effects in dengue case occurrence. A finer scale of SCI is thus needed in any subsequent spatiotemporal analysis in this geographic region. Since SCI is not equivalent to dengue vector density, SCI should be validated in future studies against actual vector surveillance or entomology survey data. However, as a first step, our SCI provides valuable insight into the possible relationship between optimal transmission environments and broad disease predictions. Further parameters, such as environmental variation (e.g., oviposition habitat availability, seasonal and daily temperature fluctuation) and socioeconomic variables, should be included in the SCI to improve prediction efficiency. Enhanced SCI may be beneficial for extrapolating the possible geographic range of transmission beyond the existing environmental context (e.g., under climate change and for newly invading pathogens).

Conclusions

This study has shown that climate-based SCI is beneficial for evaluating dengue outbreak risk and the potential effect of possible vector competition on dengue transmission. We suggest that the dengue virus in *Ae. albopictus* vector may be more transmissible in a region with warmer weather conditions (high SCI of *Ae. aegypti*). SCI of *Ae. aegypti* could be used to predict dengue transmission even in locations lacking *Ae. aegypti* but with *Ae. albopictus* present. Moreover, the SCI can be used to investigate the relative contributions of *Ae. albopictus* and *Ae. aegypti* to dengue virus outbreaks in the absence of entomology data in future research.

Abbreviations

Aedes: *Ae.*; SCI: Suitable conditions index; NB: negative binomial; NDVI: Normalized Difference Vegetation Index; BIC: Bayesian information criterion

Declarations

Acknowledgements

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Available data and materials

Data supporting the conclusions of this article are included within the article. In addition, the datasets used and analysed during the study are available from the corresponding author upon reasonable request.

Authors' contributions

Conceptualisation: WH; Methodology: WH, HB, FF, XH, GD; Formal analysis: WH, XL, XH; Writing – Original Draft Preparation: XL, Writing – Review & Editing: XL, WH, HB, FF, XH, CD, GD. All authors read and approved the final manuscript.

Ethics approval and consent to participate

This study was approved by the University Human Research Ethics Committee of Queensland University of Technology (Ref: 1800000058).

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Figures

Figure 1

Geographical distribution of dengue (a) and suitable condition index (SCI) for *Ae. aegypti* (b) and SCI for *Ae. albopictus* (c) at a county level in Guangdong province, China, 2014

Figure 2

The relationship between autochthonous dengue incidence, latitude, imported dengue cases and suitable conditions index (SCI) in Guangdong, 2014. The relationship between autochthonous dengue incidence, latitude and SCI for *Ae. aegypti* (a); the relationship between autochthonous dengue incidence, latitude and SCI for *Ae. albopictus* (b); the relationship between autochthonous dengue incidence and imported dengue cases and SCI for *Ae. aegypti* (c); the relationship between autochthonous dengue incidence and imported dengue cases and SCI for *Ae. albopictus* (d) and the relationship between autochthonous dengue incidence and SCI for *Ae. aegypti* over various levels of SCI for *Ae. albopictus* ("scial" for short) (e).

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