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Regional variability in relationships between climate and dengue/DHF in Indonesia

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Since 1970, the worldwide distribution, frequency and intensity of epidemics of dengue and dengue haemorrhagic fever (DHF) have increased dramatically. In Indonesia, as elsewhere, the geographic distribution and behaviour of the two main vectors – *Aedes aegypti* and *Aedes albopictus* – and the consequent transmission dynamics of the disease are strongly influenced by climate. Monthly incidence data were examined in relation to monthly data for temperature, rainfall, rainfall anomalies, humidity and the Southern Oscillation Index for 1992–2001. Focusing on eight provinces, significant Pearson correlations were observed between dengue/DHF incidence and at least one climate variable ($r = \pm 0.2$ to ± 0.43; $P < 0.05$). Multiple regression analyses showed that 12.9–24.5 per cent of variance in incidence was explained by two or three climate variables in each province ($P < 0.1$–0.01). Rainfall appears to be the principal climatic agent affecting the geographic distribution and temporal pattern of incidence while temperature appears to play a critical role in outbreak intensity. Wide regional and temporal variations in the strength and nature of the observed associations led to the identification of three groups of provinces where increases in dengue/DHF incidence were variously associated with increased rainfall, decreased rainfall and/or high susceptibility to climate variability. Although climatic factors play an important role in explaining the timing and intensity of dengue/DHF outbreaks, a wide range of other factors specific to local environments also appear to be involved – information that may assist in the prediction and mitigation of regional dengue/DHF outbreaks.

Keywords: dengue/DHF, climate, temperature, rainfall, humidity, Indonesia

Introduction

Dengue fever – encompassing both classic dengue and dengue haemorrhagic fever (DHF)[1] – is the single most important arbovirus in terms of both annual infection rates and total population at risk (see WHO, 2002). Disease incidence has risen dramatically over the last few decades, with countries across South America and Africa experiencing a particularly rapid growth in endemicity (Monath, 1995; Gubler & Meltzer, 1999). However, Southeast Asia and the Western Pacific remain the most seriously affected regions (Monath, 1995; Gubler, 1997; WHO, 1999; 2002). Indeed, Frost (1991) identifies Southeast Asia as a 'core' region for dengue activity, and studies by Gubler (1997), Kuno (1997), Frost (1991), CDC (2001) and WHO (2000) have found it to be the proven source of several dengue strains causing the most serious epidemics in South America, Africa and the Pacific islands.

Increasing incidence is linked to the geographic distribution and spread of the disease and the frequency and intensity of epidemics. The two primary agents of these trends identified are the rapid pace of urbanization in the global south in particular (Gubler, 1997; Kuno, 1997; McMichael, 2000; CDC, 2001; Reiter, 2001; WHO, 2002) and variations in climate (Koopman *et al*., 1991; Hales *et al*., 1996; Jetten & Focks, 1997; Keating, 2001; Hopp & Foley, 2003). Based on these studies, recent changes in global climate are widely held to be a further contributing factor (Nicholls, 1993; Jetten & Focks, 1997; Epstein, 2000; IPCC, 2001; NRC, 2001; Patz & Kovats, 2002).

Dengue/DHF is identified by the WHO as a 'Category A' or major public health problem in Indonesia, one that consistently records case fatality rates of 400–1500 per year (WHO, 1999), with classic dengue affecting some 100–400-fold as many people as DHF. Moreover, misdiagnosis and lack of reporting or underreporting mean that the scale and the impact of dengue on every level are likely to be several-fold higher than officially represented (WHO, 1999). Studies in Indonesia to date have suggested associations with rainfall and/or temperature, based on the evidence of one city or province during one epidemic period or during one observed El Niño Southern Oscillation (ENSO)[2] event (van Peenen *et al.*, 1972; Gubler *et al.*, 1979; 1981; Nathin *et al.*, 1988; Corwin *et al.*, 2001). Studies based on larger-scale observations conclude that dengue/DHF in Indonesia as a whole tends to increase in the year following El Niño (Kovats, 2000; Gagnon *et al.*, 2001; Duane Gubler, Director, Asia-Pacific Institute for Tropical Medicine and Infectious Diseases, University of Hawaii, pers. e-comm., February 2003). However, such studies, which focus on national-scale epidemic events, foregoing a more detailed regional examination of dengue/DHF incidence in relation to actual climate variables, fail to question and fully explore any regional variations in the apparent relationship between dengue/DHF and either rainfall, temperature, or El Niño. This paper documents the results of a study of the statistical association between five regional climate variables – rainfall, rainfall anomalies, temperature, humidity and the Southern Oscillation Index (SOI) – and provincial-scale dengue incidence in Indonesia between 1992 and 2001. It aims to address the shortcomings of earlier studies by exploring longer-term, regional dengue dynamics under a variety of climatic and environmental situations.

Data and methods

DHF data consisting of collated monthly reports of cases during 1992–2001 for each of Indonesia's 27 provinces (including East Timor, independent since 1999)[3] were supplied by the Indonesian Ministry of Health. Although DHF cases in Indonesia are reported according to WHO diagnostic guidelines (and the same data are used by WHO to compile their country reports), these data also include a number of classic dengue cases arising from differences in the diagnostic criteria applied by physicians and rural health workers throughout the country (Rita Kusriasturi, Ministry of Health representative, pers. comm., Melbourne, March 2003). For the purposes of this study, this limitation is assumed not to significantly skew the data and its emerging patterns; furthermore, any overreporting of DHF will likely be offset by the considerable underreporting which most researchers agree is commonplace in disease statistics in the global south (Monath, 1995; WHO, 2002). For these reasons, the study takes the DHF data as indicating dengue/DHF incidence. Using these data, the mean yearly incidence rates for each province were calculated, categorized and mapped (Figure 1).

Monthly rainfall data used for 1992–99 were collected by Kirono (2000) and supplemented for the years 2000 and 2001 by Mulyono Prabowo (pers. comm., Melbourne, March 2003), a meteorologist with the Bureau of Meteorology in Jakarta. Based on these 10-year, month-by-month data, a fourth variable depicting monthly rainfall anomalies (the amount by which each month's rainfall is above or below the defined average) was created for each province. Indonesia's rainfall is characterized by substantial seasonal and regional variability, a pattern exacerbated by ENSO climate variability (Kirono & Tapper, 1999). Many regions, especially the south and east, experience intense seasonal drought during the Austral winter (dry season), but at other times flooding rains can occur across large areas of the country.

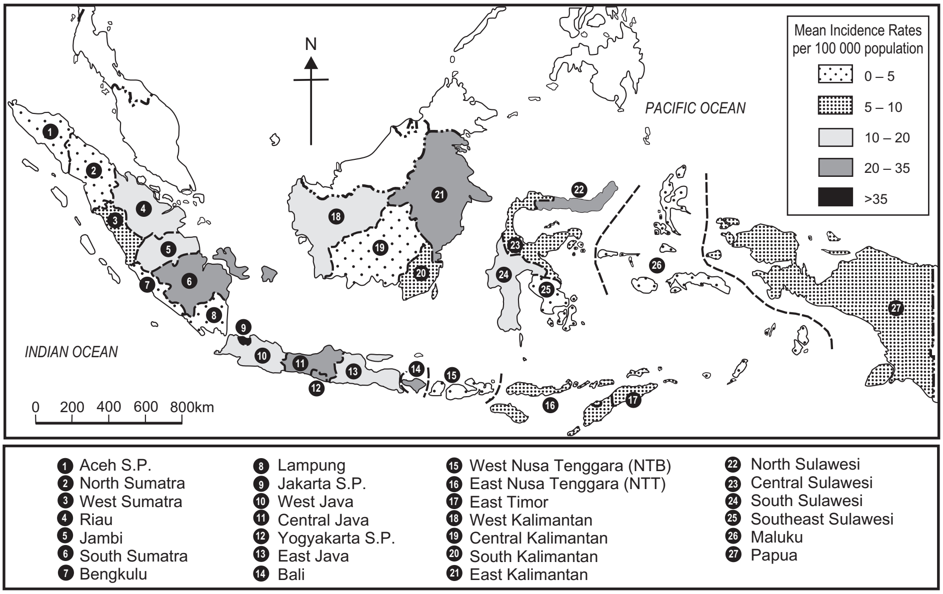

Figure 1. *Mean yearly provincial dengue/DHF incidence rates per 100 000 based on an 8–10-year period between 1992 and 2001 for Indonesia (and East Timor, independent since 1999).*
Sources: **Data provided by Indonesian Ministry of Health; map adapted from Kirono (2000).**

Monthly temperature and relative humidity data (the ratio of the actual moisture content of the atmosphere as compared to the maximum that can be held for a given temperature) for the same 10-year period were derived from the US National Centers for Environment and Prediction and National Center for Atmospheric Research (NCEP/NCAR) data (provided by the NOAA-CIRES Climate Diagnostics Center in Boulder, Colorado). Average daily temperatures across Indonesia generally remain between 23 and 28°C (Kuipers, 1993).[4] Depending on altitude and geographic location, regional temperatures can range from a minimum of 19°C to a maximum of 35°C. Relative humidity in Indonesia is 70–80 per cent; regionally, humidity rarely falls below 63 per cent and values above 90 per cent occur fairly regularly (ADB, 1994).

In the period 1992–2001, there were two ENSO events: the first in 1992–95, the second in 1997–98. The SOI used to monitor the development and movement of the ENSO phenomenon is presented in the form of monthly anomalies; SOI values for the 10-year study period were obtained from the Australian Bureau of Meteorology website (http://www.bom.gov.au/). This variable was included in the study to address the potential impact of ENSO events on dengue/DHF incidence demonstrated by previous studies. However, a detailed investigation of these events is beyond the scope of this study (but will be the focus of a separate study by the authors).

Associations between the five independent variables – rainfall, rainfall anomalies, temperature, relative humidity and the SOI – and the dependent variable – dengue/DHF incidence rates – were explored using two steps of statistical analysis. The first, a Pearson correlation analysis with a significance level of 95 per cent, was conducted for each independent variable against dengue/DHF incidence. In addition to a direct month-by-month correlation, each variable was also lagged up to six months with respect to dengue/DHF incidence. Second, a series of stepwise multiple regression analyses utilizing all five independent variables was conducted using a basic unlagged dataset for each province and a second dataset that incorporated the most significant lag for each variable. The criteria used to formulate these datasets were as follows: (i) the unlagged set of variables was referred to as dataset A and the lagged set of variables was referred to as dataset B; (ii) the first significant lag was applied to each variable; (iii) in the case of any significant lag being at least 0.05 coefficient points (*r*) above all other significant lags, then this lag was applied first; (iv) the appropriateness of using the lag with the highest *r*-value as opposed to the first significant lag was in some cases explored using an additional dataset – dataset C; (v) where there were no significant correlations at any lag, lag period 0 was used; and (vi) lag periods 5 and 6 were not considered appropriate in this analysis because of the effect of natural seasonal variation – therefore, except for one instance in Central Sulawesi, only significant lags of 0–4 inclusive were applied where appropriate.

The significance level for the multiple regression analyses was set at 90 per cent ($P < 0.1$). When exploring a dataset for relationships, rather than looking for just one or two explanatory variables, it was considered more revealing to lower the entry requirements and examine the resulting models closely. This accounts for the lower significance level at this stage of the analysis compared with the Pearson correlations. Multicollinearity between the climate variables, particularly between rainfall and rainfall anomalies, may cause the true relationship to be misrepresented as spurious correlation exists. However, it is clear that a unique relationship exists between anomalous rainfall and dengue/DHF incidence rates; that is, during periods of unusual rainfall the relationship between incidence rates and rainfall changes. To ignore this evidence would be misleading. At this exploratory stage of the analysis it was considered similarly ill advised to either remove any of the climate variables from the regression models or simplify/reduce the data to representative components. For subsequent analyses, building on the findings of this study, it may be advisable to create one or two composite variables using principal components analysis (PCA). The results obtained using the individual variables, as in this analysis, may then be used to provide a different perspective from those obtained using PCA. For the purposes of this study, the nature of the relationships between the variables demonstrated by the multiple regression analyses was comparable to those shown by the Pearson correlations. Therefore, within the limitations of the statistical procedures, the strength of these associations and repetition of certain signals were taken as sufficient evidence that the results were significant. (SPSS and Excel were used in the calculation and presentation of these statistical procedures.)

Results

Data for all of Indonesia (including East Timor)

An overview of the national-scale dengue/DHF situation in Indonesia was obtained using aggregated monthly values for provincial dengue/DHF incidence and rainfall over the 10-year period 1992–2001. As Figure 2 indicates, dengue/DHF incidence rates tend to increase during the wet season (December–March) and decrease during the dry season (June–September), which suggests an association between dengue/DHF incidence and climate (in this instance, rainfall and ENSO events). A simple linear regression analysis of these two variables showed that Indonesia's rainfall accounts for 10.4 per cent of the variance in dengue/DHF incidence ($P < 0.1$). The resulting regression equation based on the data used in Figure 2 is as follows:

$$\text{dengue/DHF incidence rate (IR)} = 0.232 + 0.007\ (\text{rainfall})$$

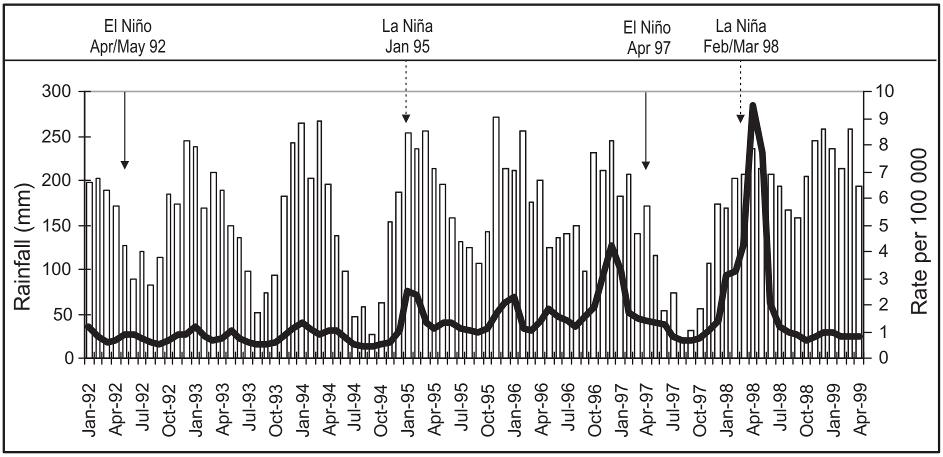

Figure 2. *Average monthly rainfall and monthly dengue/DHF incidence rates for Indonesia as a whole 1992–99 (Trenberth, 1997; Chiew et al., 1998; Gagnon et al., 2001), for El Niño years; 1995 La Niña year only recognized by Trenberth (1997).*

where 0.232 is the constant and rainfall is the average monthly national rainfall measured in millimetres.

This level of analysis cannot account for variations in the nature and strength of the association over time or for how consistent it may be across the entire archipelago. More importantly, conclusions based on this level of analysis can lead to three false assumptions, namely that (i) the absence of an observed association means there is no association between the variables; (ii) the presence of an association can be interpreted as a general law; and (iii) the presence of an association means that no other type of association is possible. Aggregated data, over time or space, can diminish or erase smaller-scale signals that may be significant for local disease dynamics. It is precisely these smaller-scale signals in dengue/DHF incidence and climate that this study is concerned with.

Using PCA on 63 weather stations spread evenly across Indonesia, Kirono (2000) demonstrated that local to regional scale influences on Indonesia's rainfall produce a diverse pattern of rainfall regimes across the country (Figure 3). The five rainfall regions Kirono identified illustrate that variation between regimes is often marked – for example, with differences of 100–300 mm in average monthly seasonal rainfall not uncommon. This gives a different and more accurate impression of Indonesia's rainfall situation than the aggregated view provided by Figure 2. Similarly, an investigation of the dengue/DHF data for 1992–2001 revealed considerable variation in patterns of incidence across the 27 provinces, which tended to conform to one of three major types (Table 1).

Selection of provinces for further analysis

As it was not practical to carry out an initial investigation of all 27 provinces, a regional focus was created using Kirono's (2000) five climatic regions as a framework. To ensure that the five provinces selected to represent these climatic regions were appropriately disparate in terms of dengue/DHF incidence and demographic characteristics, the following were also taken into account: (i) the characteristic features of the dengue/DHF incidence profiles, as summarized in Table 1; (ii) mean and maximum yearly incidence

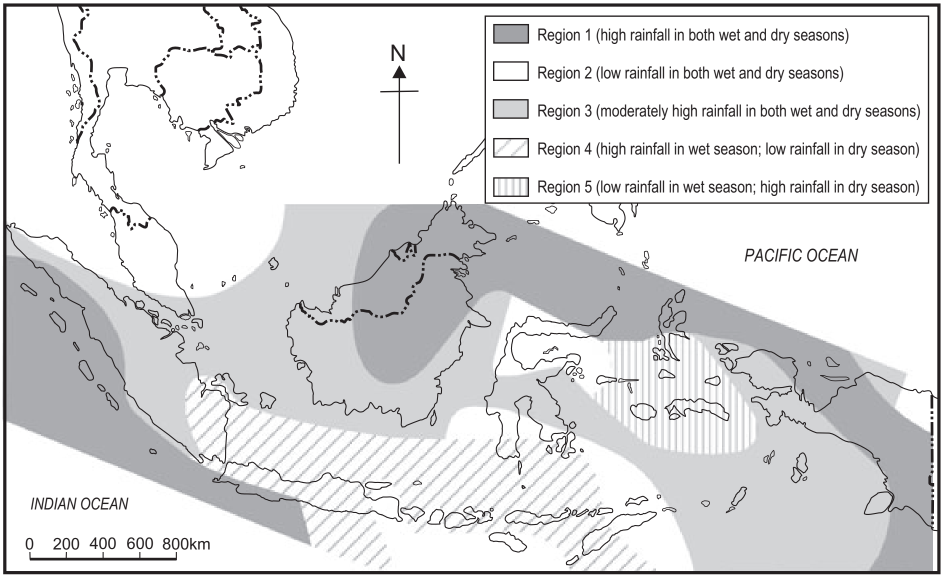

Figure 3. *Climatic regions of Indonesia (including East Timor) and locations of the 63 weather stations used to compile the data, based on Kirono (2000).*

Table 1. Categorization of Indonesia's 27 provinces (including East Timor) according to the characteristic features of their dengue/DHF incidence profiles, 1992–2001 (numbers correspond to Figure 1).

Single intense epidemic (Jan–Sep 1998)	Strong seasonal signal (around Jan, 1 mth after start of wet season – except in Jakarta, wet into wet transition season)	Seasonal and epidemic (moderate seasonality with major epidemics beyond 1998)
West Sumatra (3)	Jakarta (9)†	Aceh (1)
Jambi (5)	Central Java (11)	North Sumatra (2)
Bangkulu (7)	East Java (13)	South Sumatra (3)
Lampung (8)	East Nusa Tenggara (16)	Riau (4)
Jakarta (9)†		Bali (14)
West Java (10)		West Kalimantan (18)
Yogyakarta (12)		Central Kalimantan (19)
West Nusa Tenggara (NTB) (15)		South Kalimantan (20)
East Timor (17)		East Kalimantan (21)
Central Sulawesi (23)		North Sulawesi (22)
Southeast Sulawesi (25)		South Sulawesi (24)
Maluku (26)		Irian Jaya (27)

†A strong seasonal signal in 1998 was enhanced, resulting in a particularly intense epidemic – hence Jakarta appears in two categories.

rates for each province; (iii) provincial population densities; and (iv) results of a spatial autocorrelation analysis in which the 10-year dengue/DHF incidence data for all 27 provinces were cross-correlated using a west–east sequence, and the resulting correlations were categorized and 'mapped'.

The criteria applied to the province selection process were that (i) the five provinces represented each of the five climatic regions identified by Kirono (2000); (ii) their dengue/DHF incidence profiles were different, yet representative of temporal characteristics shared by more than one province; (iii) they were representative of different combinations of various provincial population densities, and mean and maximum yearly incidence rates; and (iv) if their patterns of dengue/DHF incidence were highly correlated, the provinces were deemed sufficiently different from each other in at least one other respect – either population density, mean and maximum yearly incidence rate or intensity of incidence – to warrant selection. On the basis of these criteria, one province was selected to represent each of Kirono's five climatic regions. There were several apparent outliers – Aceh, West Nusa Tenggara (NTB) and Jakarta – which were added to accommodate the full range of dengue/DHF situations that were apparent. Table 2 summarizes the major characteristics of the eight provinces, and their 10-year incidence rate profiles in Figure 4 illustrate the diversity in the patterns of dengue/DHF incidence across provincial Indonesia. Since the Special Capital Territory (Daerah Khusus Ibukota) of Jakarta was the province with the highest number of cases and dengue/DHF incidence rates, the results for this province are presented in full below.

Detailed analysis for the province of Jakarta Daerah Khusus Ibukota

Figure 5 indicates that only three of the five climate variables demonstrated significant Pearson correlation with dengue/DHF incidence. Rainfall was positively correlated at lags 1, 2 and 3 ($r = 0.19$, 0.34 and 0.27 respectively; $P < 0.05$), indicating that as rainfall increased there was a significant increase in dengue/DHF incidence between one and three months later; the strongest association was with a two-month lag. Although the differences between the correlations at these three lag periods were not statistically significant, they might still have had a bearing on dengue/DHF dynamics. The rainfall anomalies (RA) variable was also significantly associated with dengue/DHF incidence. In this case the correlation value, at lag 3, was negative ($r = -0.25$; $P < 0.05$), indicating that with increasingly below-normal rainfall, dengue/DHF incidence tended to increase three months later. Temperature was significantly associated with dengue/DHF incidence in lags 0–3 ($r = 0.37$, 0.43, 0.41 and 0.31 respectively; $P < 0.05$). The correlation values were positive, indicating that as temperature increased so did dengue/DHF incidence when unlagged, or lagged by one to three months, with the maximum correlation value occurring after one to two months.

Neither humidity nor the SOI were significantly correlated with dengue/DHF incidence at any lag period. For both variables, at lags 0–6, the confidence intervals included zero as a possible value, indicating that there was a 95 per cent possibility of there being no association.

Using the correlation charts for rainfall, RA, temperature, humidity and the SOI, the following datasets were created for the multiple regression analyses. The difference between the first and highest significant correlation values for temperature and rainfall was greater than 0.05 (Figure 5). Consequently, according to the criteria established in the methodology, two sets of lagged variables were created which explored the explanatory power of both the highest (dataset B) and first (dataset C) significant correlations (Figure 6). This established whether the difference between the two values, although not statistically significant according to the Pearson analysis, was sufficient to alter the explanatory power of the regression model. Table 3 shows the results of multiple regression analyses conducted using each of the datasets (A, B and C).

Dataset B resulted in the model with the greatest explanatory power (adjusted R^2). Thus the difference between the highest (dataset B) and first (dataset C) significant correlations was sufficient to contribute 6.8 per cent more variance. The number of

Table 2. Principal characteristics of the eight selected provinces as compared with all 27 provinces, 1992–2001.

Province (rainfall region)	Population density (per km^2)	Mean dengue/DHF incidence (per 100 000)	Peak dengue/DHF incidence (per 100 000)	Pattern/incidence correlated with	Dengue/DHF profile
East Kalimantan (1)	0–19 lowest	20–35 2nd highest	40–100 2nd highest	Central Sulawesi	1 prolonged epidemic 2000–02; 2 lesser peaks 1995 & 1998. Persistent fluctuating baseline.
Central Sulawesi (2)	20–59 2nd lowest	5–10 2nd lowest	30–40 3rd highest	Jakarta, East Kalimantan, NTB, Maluku	1 major peak 1998; 1 minor peak 2000–01. Baseline remains around 0.
West Kalimantan (3)	20–59 2nd lowest	20–35 3rd highest	30–40 3rd highest	None	2 major peaks 1997 & 1999. Persistent fluctuating baseline.
Central Java (4)	500–999 2nd highest	20–35 2nd highest	40–100 2nd highest	Jakarta, NTB, Maluku	Highly seasonal; peaks annually, major peak 1997. Persistent baseline.
Maluku (5)	20–59 2nd lowest	0–5 lowest	20–30 2nd lowest	Jakarta, Central Sulawesi, NTB	1 major peak 1998; sporadic low-level peaks. Baseline predominantly 0.
Aceh (2)	60–99 3rd lowest	0–5 lowest	0–20 lowest	None	1 major peak 1995; 2 lesser peaks 1994 & 1998. Semi-seasonal, fluctuating low baseline.
West Nusa Tenggara (NTB) (2/4)	100–499 3rd highest	0–5 lowest	30–40 3rd highest	Jakarta, Central Java, Central Sulawesi, Maluku	1 major peak 1998. Baseline remains around 0.
Jakarta (4)	>1000 highest	>35 highest	>100 highest	Central Java, Central Sulawesi, NTB, Maluku	1 major peak 1998; low-level seasonal signal. Persistent baseline.

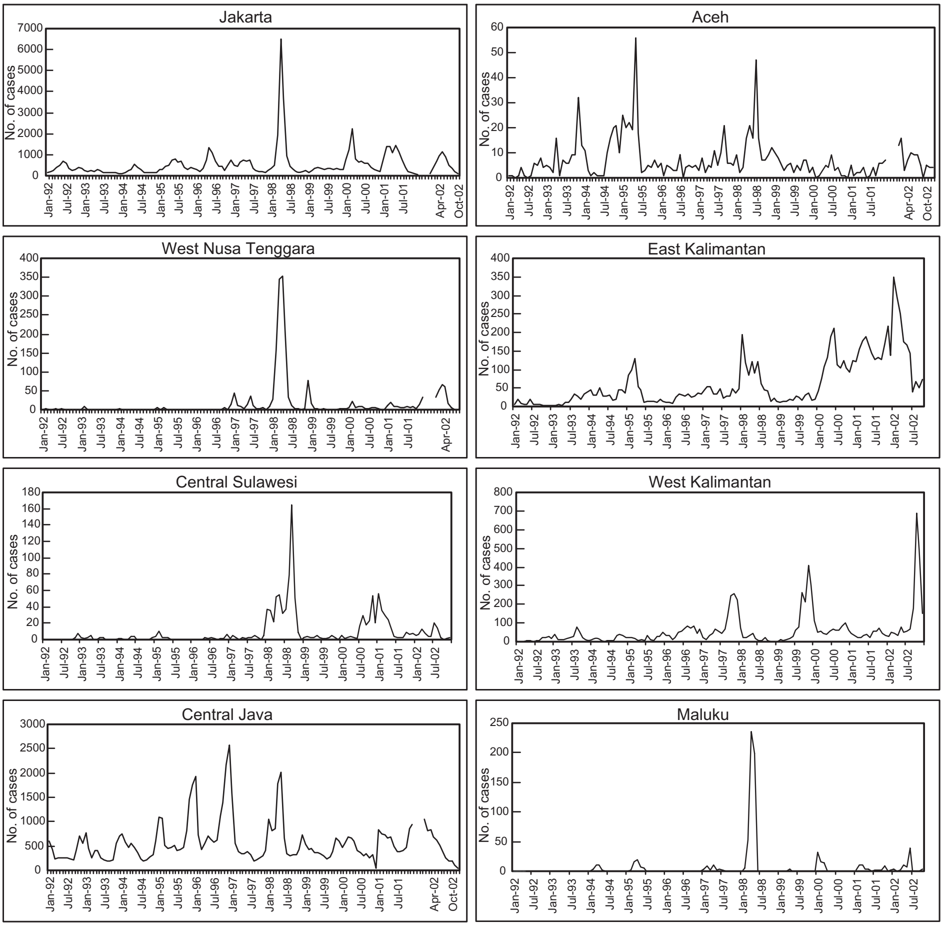

Figure 4. *Monthly cases of dengue/DHF in the eight provinces selected for analysis, 1992–2001.*
Note: **Vertical scales differ from province to province.**

significant predictors in each model was the same; temperature and the SOI appeared in all three models. However, when rainfall was lagged by two months (dataset B), rainfall replaced humidity as a significant predictor. The B coefficients and significance levels showed that temperature was associated positively with dengue/DHF incidence for all three modelled datasets at the 99 per cent level of significance ($P < 0.01$). There was also a positive association with rainfall at a 95 per cent level of significance ($P < 0.05$), but only in the dataset B model. Humidity (unlagged) exhibited a positive association in the models for datasets A and C, again at the 95 per cent level of significance ($P < 0.05$). Finally, the SOI was negatively associated with dengue/DHF incidence in all three models at the 90–95 per cent level of significance ($P < 0.05$; $P < 0.1$). Based on these five variables, climate-related increases in dengue/DHF incidence rates in Jakarta can be attributed primarily to increasing temperatures and rainfall, and decreasing SOI values. Negative SOI values would normally be associated with increased rainfall. However, in Jakarta, after an 11-month period of below-normal rainfall and negative SOI values related to the 1997/98 ENSO event, rainfall began to increase but the SOI values were still negative. This shows the potential for regional variation in associations between

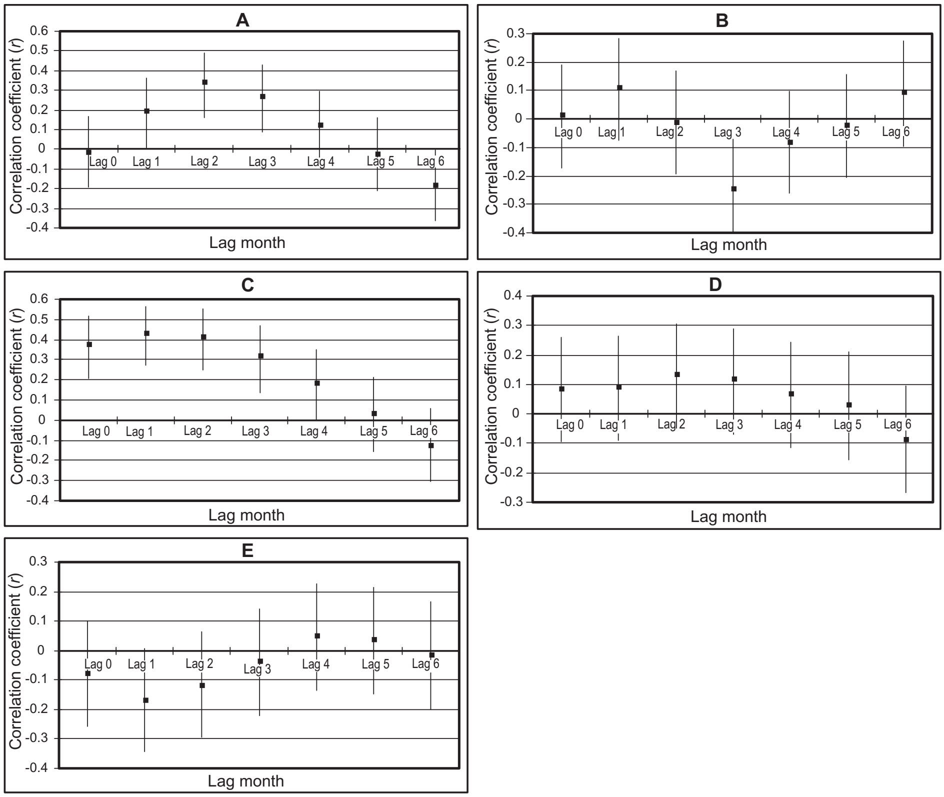

Figure 5. *Relationship between (A) rainfall, (B) rainfall anomalies (RA), (C) temperature, (D) humidity and (E) SOI (lagged 0–6 months) and dengue/DHF incidence rates in Jakarta from 1992 to 2001, shown by the Pearson correlation coefficient (r) with confidence intervals at lags 0–6 months. When the confidence interval crosses zero, there is 95 per cent probability of there being no relationship between the variables (P < 0.05; sample sizes (n) from lag 0 to 6: (A, B) 118–112; (C–E) 121–115).*

Unlagged	Dataset A	
Lagged	**Dataset B**	**Dataset C**
Temperature	1 month	0 months
Rainfall	2 months	1 month
Humidity	0 months	0 months
Rainfall anomalies	3 months	3 months
SOI	0 months	0 months

Figure 6. *Datasets created for the multiple regression analysis of dengue/DHF and climate in Jakarta.*

rainfall and the SOI, and that it is not always the case that negative SOI values are associated with below-normal rainfall. There was also a significant association with increasing humidity apparent in the models for datasets A and C. However, with a two-month lag in rainfall and a one-month lag in temperature (dataset B) the strength of this association was outweighed by that with rainfall. Nevertheless, it is relevant to dengue/DHF dynamics in Jakarta that increasing humidity can enhance incidence rates.

Although there were no significant Pearson correlations between dengue/DHF incidence and either humidity or the SOI, these variables appeared as significant predictors

Table 3. Regression coefficients, significance levels and adjusted R^2 values for the optimal unlagged (dataset A) and lagged (datasets B and C) regression models for Jakarta.

Predictors	Dataset A ($n = 118$)		Dataset B ($n = 115$)		Dataset C ($n = 115$)	
	B coeff.	Sig.	B coeff.	Sig.	B coeff.	Sig.
(Constant)	–214.364	<0.001	–120.652	<0.001	–208.696	<0.001
Temperature	5.574	<0.001	4.839	<0.001	5.731	<0.001
Rainfall	x	x	0.015	0.011	x	x
Humidity	0.889	0.022	x	x	0.777	0.050
Rainfall anomalies	x	x	x	x	x	x
SOI	–0.109	0.060	–0.109	0.058	–0.128	0.033
Adjusted R^2 (%)	17.7		24.5		18.7	

SOI, Southern Oscillation Index; x, variable is not a significant predictor of dengue/DHF variance ($P < 0.1$).

in the regression models, because the Pearson correlation value measures only the degree of linear association between two variables. Multiple regression analysis is able to explore the non-linear association between variables by determining the amount of variance (R^2) in the dependent variable (dengue/DHF incidence) that can be explained by any one independent variable. The magnitude and direction (positive/+ or negative/–) of this association, for every one unit change in the independent variable, is quantified by the B coefficient. Thus, the R^2 value indicates the proportion of the total variance, measured as a percentage, which is accounted for by the magnitude of change (dataset B). This is the case for all subsequent analyses.

Summary of provincial results

Table 4 presents a detailed summary of the results of these analyses for the eight selected provinces. The regression equations tended to underrepresent epidemic peaks, especially in Jakarta, NTB, Central Sulawesi and Maluku, where the actual incidence at the epidemic peak was at least fourfold that predicted by the models. In Aceh, Central Java, West and East Kalimantan, underrepresentation of incidence at epidemic peaks by the models was in the order of approximately half the actual incidence. By the same token, the models tended to overrepresent incidence during periods of low actual incidence. This was especially the case in Jakarta and East and West Kalimantan, where modelled incidence could be three- to fourfold the actual incidence. In provinces that exhibited a degree of seasonality in their dengue/DHF profiles – Central Java, Jakarta and Aceh – the models appeared better able to approximate the timing and magnitude of changes in incidence over the 10-year study period. In Central Java, this was primarily related to the strongly seasonal rainfall regime, whereas in Jakarta and Aceh it appears that a combination of moisture availability and strong seasonality in the temperature regime contributed to some regularity in the timing of annual increases in dengue/DHF incidence. Notably, these were also the only provinces in which rainfall appeared as a significant predictor in the optimal regression models.

Identifying provincial trends

Based on the Pearson correlation and multiple regression analyses, Tables 5 and 6 provide an overall indication of which climate variables were significantly associated in each of the eight selected provinces and the direction and magnitude of these associations.

Table 4. Summary of significant relationships between climate and dengue/DHF incidence rate (IR) in the eight provinces selected for analysis.

Province	Jakarta	Aceh	NTB	East Kalimantan	Central Sulawesi	West Kalimantan	Central Java	Maluku
Pearson correlation analyses ($P < 0.05$)								
Sig. correlations (r) with dengue/DHF @ optimal lag-month indicated	T: 0.43/1 mth R: 0.34/2 mths RA: –0.24/3 mths	T: 0.25/1 mth R: 0.3/No lag RA: 0.33/0 mths S: –0.32/1 mth	S: 0.42/5 mths	T: 0.28/1 mth R: 0.2/3 mths RA: –0.27/2 mths H: –0.27/5 mths	T: 0.28/3 mths R: 0.19/0 mths RA: 0.29/No lag S: 0.2/No lag	T: 0.33/No lag R: –0.23/4 mths H: –0.28/2 mths	T: 0.32/No lag R: 0.41/1 mth H: 0.35/No lag	RA: –0.2/3 mths S: 0.27/1 mth
Multiple regression analyses – optimal model† ($P < 0.1$)								
% variance explained (R^2)	24.5%	14.4%	23.1%	15.3%	19.2%	12.9%	17.8%	20.5%
Sig. predictors & assoc. change in IR/100 000 (unstandardized B coeff.; C = constant)	T: +1°C = 4.83 S: –1 unit = 0.109 R: +1 mm = 0.015 C = –120.652	T: +1°C = 0.051 S: –1 unit = 0.004 R: +1 mm = 0.001 C = –1.323	T: +1°C = 0.694 H: +1% = 0.111 S: –1 unit = 0.054 C = –27.591	T: +1°C = 1.768 RA: –1 mm = 0.005 C = –39.684	T: +1°C = 0.603 RA: +1 mm = 0.004 S: –1 unit = 0.026 C = –14.648	T: +1°C = 0.982 H: –1% = 0.258 C = –3.798	R: +1 mm = 0.008 RA: –1 mm = 0.006 C = 0.457	T: +1°C = 0.939 H: +1% = 0.209 S: –1 unit = 0.052 C = –41.818
Relative sig. of each predictor (standardized B coeff.)	T: 0.397 R: 0.223 S: –0.159	R: 0.361 S: –0.220 T: 0.147	T: 0.521 S: –0.467 H: 0.186	T: 0.346 RA: –0.214	T: 0.337 S: –0.307 RA: 0.192	T: 0.258 H: –0.217	R: 0.668 RA: –0.435	T: 0.538 S: –0.447 H: 0.389
Optimal dataset (lags in months)	T: 1 R: 2 RA: 3 H: 0 S: 0	T: 0 R: 0 RA: 0 H: 0 S: 1	T: 0 R: 0 RA: 0 H: 0 S: 1	T: 0 R: 1 RA: 1 H: 4 S: 0	T: 3 R: 0 RA: 0 H: 0 S: 5†	T: 0 R: 3 RA: 0 H: 2 S: 0	No lags	T: 0 R: 0 RA: 3 H: 0 S: 1
Potential high-risk factors that contribute to increased IR	Intense period of climate variability – 97/98 ENSO; prior period below-normal rainfall.	Prior period below-normal rainfall.	Intense period of climate variability – 97/98 ENSO; prior period below-normal rainfall.		Intense period of climate variability – 97/98 ENSO; prior period below-normal rainfall.			Intense period of climate variability – 97/98 ENSO; prior period below-normal rainfall.

T, temperature; R, rainfall; RA, rainfall anomalies; H, humidity; S, SOI. The optimal model is that which explains the most variance, inclusive of lagged and unlagged model results.

†Lags of more than four months were not considered relevant for this stage of the analysis. However, given the pattern of dengue/DHF incidence in Central Sulawesi (Figure 4) and the IR observed in many other provinces during the 1997/98 ENSO event, it was considered more probable that the significant negative correlation with the SOI at lag 5 was more relevant for increased dengue/DHF incidence than the positive correlation at lag 0. The results of the multiple regression analyses for all three datasets revealed this to be so with eight per cent more explained variance in dataset C.

Table 5. Climate variables exhibiting significant Pearson correlations with dengue/DHF incidence in the eight selected provinces ($P < 0.05$).

Province	Rainfall	Rainfall anomalies	Temperature	Humidity	SOI
West Kalimantan	– –		+++	– –	
East Kalimantan	– –	– –	++	– –	– – –
Central Java	++++	+++	+++	+++	– –
Aceh	++	– –	++		– –
Jakarta	+++	++	++++		– – –
Central Sulawesi	+	– –	++		
Maluku					
NTB					

Sign (+/–) denotes the direction of the linear association; repetition denotes the strength of the strongest correlation observed between the variables from lag 0 to lag 4 (except for Central Sulawesi, which extends to lag 5 for the SOI). <±0.2: + or –; ±0.2–0.29: ++ or – –; ±0.3–0.39: +++ or – – –; >±0.4: ++++ or – – – –.

Table 6. Results of the optimal multiple regression model for the eight selected provinces.

Province	Rainfall	Rainfall anomalies	Temperature	Humidity	SOI
West Kalimantan			++	–	
East Kalimantan	+	–	++	+	–
Aceh	+	–	+	+	–
Central Java	+	+	++++		–
Jakarta			+		–
Central Sulawesi			+		–
NTB			+		
Maluku					

Blank cells indicate variables not statistically significant enough to appear in the final model ($P < 0.1$). According to the unstandardized B coefficient, the direction (+/–) and magnitude of change in dengue/DHF incidence rates for each unit change in the independent variable per 1 000 000 persons is as follows: <1 case: +/–; 1–1.99 cases: ++ or – –; 2–3.99 cases: +++ or – – –; >4 cases: ++++ or – – – –.

Temperature and rainfall each exhibited six of a possible eight significant linear Pearson correlations with dengue/DHF incidence; RA were next with five significant correlations, followed by the SOI and humidity with four and three significant correlations respectively (Table 5). The correlations with temperature were consistently positive while those with the SOI were consistently negative. In contrast, rainfall, RA and humidity demonstrated both positive and negative correlations in different provinces.

The results of the multiple regression analyses (Table 6) showed that temperature appeared as a significant predictor of variations in dengue/DHF incidence in seven of the eight provinces. The SOI appeared in five provinces, followed by rainfall, RA and humidity in three provinces each. As in the Pearson correlations, the associations with temperature were consistently positive and those with the SOI consistently negative. Unlike the Pearson correlations, however, all associations with rainfall were positive, although below-normal rainfall was a significant predictor in East Kalimantan and Central Java.

The Pearson correlation and multiple regression analyses suggested some patterns of association of dengue/DHF and climate variables. Central Java and West and East Kalimantan tended to demonstrate stronger correlations for dengue/DHF with at least three of the five climate variables (Table 5). The SOI did not appear as significant (Tables 5,6), but the associations between dengue/DHF and RA and humidity were uniquely negative. Although Jakarta exhibited some similar characteristics to Central Java as noted in Table 1, owing to the intensity of the 1998 epidemic it was more similar to NTB, Maluku, Central Sulawesi and Aceh, which all displayed significant associations with the SOI (Table 6) and consistently positive associations in the multiple regression analyses with rainfall, or RA, or humidity. West and East Kalimantan were distinct from Central Java in their uniquely negative associations with rainfall (Tables 5,6). Central Java was also unique as it was the only province that exhibited no significant association with temperature (Table 6). Aceh bore similarities with Central Java in that temperature was the least important variable and, uniquely in these provinces, rainfall was the most important variable. Aceh and Central Java, along with Jakarta, were also the provinces with the most seasonal dengue/DHF profiles. Finally, Maluku and NTB were related because they exhibited only one significant Pearson correlation with any variable other than the SOI (Table 5) and also because of the nature of their shared associations with temperature, humidity and the SOI (Table 6).

From this analysis, three groups of provinces emerged with rainfall being a major determinant. In the first group (Central Sulawesi, Maluku, NTB and Jakarta), rainfall regimes were more susceptible to patterns of variability such as ENSO, and the resulting anomalous rainfall conditions were associated with intense epidemic activity. Temperature explained the greatest amount of overall variance in dengue/DHF incidence. Associations with rainfall were predominantly positive. In the second group (Aceh and Central Java), where climate regimes were little altered by patterns of variability throughout the 10-year period, the major epidemics occurred outside of ENSO periods. Associations with rainfall were predominantly positive, and rainfall explained the greatest amount of overall variance in dengue/DHF incidence. Finally, in the third group (West and East Kalimantan), where climate regimes were also little altered by patterns of variability, the major epidemics occurred outside of both ENSO events. However, associations with rainfall were consistently negative and most of the overall variance in dengue/DHF incidence was explained by temperature.

Discussion

The combined results of the Pearson and multiple regression analyses indicate that temperature, rainfall and the SOI, in descending order of relative importance, exhibit the most significant statistical associations with dengue/DHF incidence in the eight selected provinces. In this study, relative humidity is not a significant variable in the spatial or temporal distribution of dengue/DHF in Indonesia.

Associations between temperature and dengue/DHF incidence are consistently positive, as noted by Keating (2001) in Puerto Rico and Hales *et al.* (1999) in French Polynesia. Increases in temperature are always accompanied by increases in dengue/DHF incidence (provided other conditions are favourable), most likely because of the exponential transmission potential of increased rates of development of virus and vector, increased biting rates and increased breeding activity that result from even small increases in temperature (Sehgal, 1997; Focks *et al.*, 2000). However, unlike Keating's (2001) study where the optimal results were achieved with a three-month lag in temperature, optimal results in this study were achieved with no temperature lag in six of the seven provinces and just a one-month lag in Jakarta. Only in Central Sulawesi was a three-month lag in temperature found to increase the explanatory power of the regression model. This suggests that different environmental preconditions are most likely responsible for determining the time it takes for increased temperatures to affect the transmission cycle (Keating, 2001). In French Polynesia, Hales *et al.*, (1996) found a more synchronous relationship between dengue incidence and temperature but also noted that the correlation varies depending on local ecological and population characteristics. Under constant moisture conditions, the correlation is more immediate. Although some authors have postulated that warmer temperatures shorten the lifespan of the mosquito, which reduces the number that survive long enough to transmit the virus, on the evidence of these and other studies it would seem that increases in temperature can lead to more rapid and sometimes explosive increases in dengue/DHF transmission.

Associations between rainfall and dengue/DHF incidence are not consistent across the eight provinces. Wellmer (1983) and Fauran (1996) similarly note situations in which below-normal rainfall can be associated with both increased and decreased incidence, and conversely with above-normal rainfall. This can lead to wide regional variations on a global level in the effect of precipitation on dengue/DHF incidence, as demonstrated by Patz *et al.* (1998). This is probably attributable to the particular environmental characteristics of each region and what it takes to create conditions favourable for mosquito breeding.

In high rainfall regions such as East and West Kalimantan, low rainfall causes high-water levels to recede allowing the formation of standing pools ideal for breeding. Conversely, excess rainfall will flood potential breeding sites. A negative association between dengue/DHF and rainfall was also found by Poveda *et al.* (1999) in the Dominican Republic and by Gordon (1988) in Colombia. Conversely, in a dry environment such as Central Sulawesi, increased rainfall can lead to the formation of ideal breeding conditions while a further drop in rainfall will cause any existing pools of water to disappear, thereby curtailing all breeding activity. Positive associations between dengue/DHF and rainfall have also been established in Mexico, Thailand, Malaysia and Sri Lanka (Gould *et al.*, 1970; Wellmer, 1983; Foo *et al.*, 1985; Koopman *et al.*, 1991; Barbazan *et al.*, 2002). However, in urban and semi-urban areas where infrastructure has failed to keep up with population increases and the pace of development, the high density of domestic water storage containers and volume of discarded rubbish mean that the breeding cycle is viable all year round. Thus, precipitation levels are less directly correlated (Gubler, 1998; Gratz, 1999). Consequently, in some urban areas, associations between rainfall and dengue/DHF can be diminished or even nonexistent, as van Peenen *et al.* (1972) noted in their study in Jakarta.

An extensive study of DHF across Thailand's 72 provinces (Wellmer, 1983) divided the country into four climatic regions and 1–5 subdivisions within these regions based on precipitation totals. As in our study, clear differences occurred in the patterns of dengue/DHF incidence between some climatic regions, and some regions with quite different rainfall regimes produced similar patterns of incidence. As in Indonesia, other factors, such as population density and associated domestic water storage practices, may partly explain these similar observations. In the wetter southern region of Thailand, less epidemic and more seasonal, monsoon-related patterns of DHF incidence were observed, with increases in DHF associated with a one-month lag in monsoon onset. In our study, Central Java and Jakarta showed the same tendency for a higher correlation with dengue/DHF incidence one to two months following the onset of the wet season. As there would generally be less need for year-round water storage in these regions, the breeding cycle would more naturally follow the rainfall regime.

However, our study also found that Jakarta's rainfall regime was more affected by the 1997/98 ENSO than that of Central Java, resulting in a longer dry period prior to the rains. A prolonged dry period prior to the onset of rains appears to be a feature of the most intense epidemic periods in the 10-year dengue/DHF profiles of NTB, Maluku and Central Sulawesi as well as Jakarta. This supports Aiken *et al*. (1980) in their demonstration of a relationship between a moisture deficit prior to surplus and increased DHF in Southeast Asia. This may be attributable to an increased accumulation of unhatched eggs as the dry period persists, followed by their almost simultaneous release when the rains appear. This might be exacerbated by the associated necessity for more domestic water storage containers, which, coupled with different demographic and environmental circumstances in these provinces, may have contributed to the dramatic epidemic peaks in incidence. Conversely, our study found that Central Java's rainfall regime was little altered during the 1997/98 period and the pattern of dengue/DHF incidence maintained its strong seasonal pattern.

Rainfall, therefore, appears to be the principal climatic agent associated with the distribution and timing of periods of increased incidence in Indonesia, and temperature appears to relate to the magnitude of these increases, hence the consistently positive association. The reason for this particular association between the variables is probably that throughout Indonesia, except at high altitudes, temperatures year-round are favourable for mosquito breeding. Thus, the geographic distribution and timing of increases in incidence would not be greatly influenced by changes in this variable. However, rainfall regimes, and the resulting favourability of conditions for mosquito breeding, vary widely across regional Indonesia and exhibit different levels of susceptibility to patterns of variability such as ENSO. Consequently, the regional distribution and timing of increases and decreases in dengue/DHF incidence would be more influenced by rainfall.

The findings of this study support those of Hales *et al*. (1996), who found significant correlations between the SOI and dengue/DHF incidence in 10 of 14 South Pacific island nations studied. They also note that in areas less affected by ENSO events, such as Thailand and Puerto Rico, correlations between these variables are low. This observation may also apply on a regional scale, as suggested by both our study and that of Cazelles *et al*. (2005) in Thailand. Studies by Corwin *et al*. (2001), Kovats (2000), Gagnon *et al*. (2001) and WHO (2000) similarly found evidence of a link between dengue/DHF in Indonesia and ENSO events. The explanation lies in their impact on regional rainfall regimes.

Intense epidemic activity, as seen in Jakarta, Maluku, NTB and Central Sulawesi, is associated with anomalous rainfall conditions. Patz and Kovats (2002) and Kirono (2000) demonstrate that ENSO events are significantly associated with anomalous regional rainfall in Indonesia – both excesses and deficits. These events, in turn, are most commonly indicated by negative SOI values, hence the consistently negative associations between dengue/DHF and the SOI. The definition of anomalous rainfall naturally varies depending on what is 'normal'. Therefore, associations between dengue/DHF incidence and the SOI are consistently negative, whereas those with rainfall and rainfall anomalies can be both positive and negative.

The provinces where anomalous rainfall conditions show the greatest associations with dengue/DHF – Maluku, NTB, Central Sulawesi and Jakarta – are also those where the most dramatic epidemic activity occurred during the 1997/98 ENSO period. In the other four provinces, where rainfall regimes were relatively unaltered over the 10-year period, even during ENSO events, this epidemic pattern is either absent as in Central

Java, less evident as in Aceh, or the dengue/DHF profile is characterized by epidemic periods that do not appear to be significantly associated with climate as in West and East Kalimantan.

The primacy of temperature, rainfall and the SOI over humidity in this study is contrary to a study by Hales *et al*. (2002) in which vapour pressure, a measure of humidity, was used to model global dengue transmission with a claimed 89 per cent accuracy. Several other authors recommend including a measure of humidity in studies of dengue/DHF given its significance for both mosquito and virus development (e.g. Lachmajer & Hien, 1975). However, this study revealed that relative humidity appears to be of little direct significance to dengue/DHF incidence rates in Indonesia, most likely because average humidity levels, at 70–80 per cent, are consistently within limits regarded as highly favourable for both vector and virus. Being a function of both temperature and moisture content, vapour pressure may be a more appropriate and informative moisture variable for future studies.

Studies by WHO (2004) and Henderson (1998) propose that dengue epidemics in Indonesia follow a five-year periodicity. The cyclical dominance of particular dengue strains has been noted by Gubler *et al*. (1979) in Indonesia and Lam (1993) in Malaysia, and Cummings *et al*. (2004) observed travelling waves in DHF incidence in Thailand. This is supported by a recent study by Cazelles *et al*. (2005) in Thailand, which demonstrated a correspondence between waves of dengue epidemics and El Niño over a two- to three-year periodic mode. Our study shows indications of a rhythm in dengue/DHF incidence in Central Java. This could be explained by natural 'boom and bust' cycles in mosquito dynamics which, combined with ENSO events and the sequential emergence of dengue strains, may create the conditions for an epidemic given favourable demographic factors. Clarification of the influence of particular viral strains requires further study.

Another factor that may affect dengue/DHF occurrence is the variation in the viral susceptibility of *Aedes aegypti* and *Aedes albopictus* and the variations in viral susceptibility between different geographic strains of each species, which in turn affect the virulence of the circulating strains of the virus (Gubler *et al*., 1978; Monath, 1995; Kuno, 1997; Rodhain & Rosen, 1997). *Ae. albopictus* is known to be the less domestic of the two species, in that its preferred breeding containers tend to be the rural outdoors. It is thus less likely to feed or rest indoors where human congregation is most likely. This has led to the conclusion that this species is less significant for epidemic dengue/DHF in urban environments, and that it is more directly influenced by climate than its 'domesticated' cousin (WHO, 1993; Rodhain & Rosen, 1997). However, during a study in Central Java, Gubler *et al*. (1981) observed *Ae. albopictus* breeding indoors as well as out: indeed, it was found to be the principal vector for an epidemic in a rural agricultural area (Jumali *et al*., 1979). Despite its oviposition preferences, lower fertility and higher viral susceptibility (producing less virulent strains), the increasing presence of *Ae. albopictus* in urban environments may be a sign that it is developing a high adaptive potential similar to that of *Ae. aegypti* (Rodhain & Rosen, 1997). Given that *Ae. albopictus* has a wider geographic and climatic range, wider flight range, greater longevity, eggs that can survive freezing conditions and more 'aggressive' feeding habits (Monath, 1995), and that it transmits encephalitis as well as dengue and yellow fevers, and demonstrates ovitransmission of all four dengue serotypes (where only DEN-1 is transmitted this way by *Ae. aegypti*), the implications of its increased presence are yet to be fully realised.

The human immune system responds differently to each virus strain and this has been found to be a significant factor in determining the severity of an initial infection and the impact of any subsequent dengue infection. Under a mechanism called antibody-dependent enhancement, a secondary infection with a different viral strain can infect a larger number of cells with a greater degree of infectivity (Guzman & Kouri, 2002), thus increasing the risk of DHF from secondary infection 100-fold (Monath, 1995). The sequence of circulation of viral strains may also be a factor in the severity of the primary and secondary infections that result (WHO, 1993; Gubler & Clark, 1995; Guzman & Kouri, 2002). Co-circulation of more than one strain can also take place and the viruses themselves are highly capable of mutating, raising the potential for the emergence of new strains (Gubler, 1997; Kuno, 1997; Guzman & Kouri, 2002). Associations have also been noted between malnutrition and decreased risk of DHF, and between asthma, diabetes, sickle-cell anaemia and increased risk of DHF (Thisyakorn & Nimmannitya, 1993; Guzman & Kouri, 2002).

Conclusions

This study shows that a combination of rainfall, temperature, humidity and the SOI can explain 12.9–24.5 per cent of the variance in dengue/DHF transmission observed in each of the eight selected provinces in Indonesia over the 1992–2001 study period ($P < 0.01$ to 0.1). It also shows that the relationships between climate variables and dengue/DHF are not consistent across Indonesia. Thus, the presence of climatic conditions conducive to the occurrence of dengue/DHF is not sufficient to explain its distribution. Clearly, other factors are involved in accounting for both the remaining 75–87 per cent of unexplained variance and the provincial differences. As alluded to previously, these include a range of factors – for example, environmental conditions such as geology, topography, hydrology, soil type, vegetation and land use; socioeconomic and cultural factors such as population densities and demographic characteristics, population mobility, level of immunity/prior infection history, occupation, level/rate of urbanization, water-storage practices, water supply, health provision and surveillance, education, waste/rubbish disposal, social gatherings and religious pilgrimages, attitudes to illness, economic resources and their allocation and political issues; as well as entomological and virological factors such as mosquito species and behaviour, virus serotype, virus/vector interactions and capacities for adaptation and mutation.

There are optimal climatic conditions for mosquito breeding in terms of temperature and moisture availability. The ways in which these conditions may be reached vary widely across different regions of the world, depending on many of the above factors, and also vary from season to season and under the influence of patterns of variability such as ENSO. Similarly, there are optimal environmental and human conditions for the transmission of dengue/DHF, and the degree to which these conditions are met will influence the probability and magnitude of transmission. The two spheres are not mutually exclusive and the factors influencing optimal breeding and optimal transmission interact in many direct and indirect ways. However, the notion of there being optimal conditions, and various pathways and degrees to which these conditions can be reached, helps to explain the wide variations and complexities observed in regional dengue/DHF dynamics.

In light of the demonstrated capacity for variation in regional dengue/DHF dynamics and the consequent problems inherent in attempting to arrive at generalized conclusions regarding the relationship between dengue/DHF and climate, the implications of climate change for dengue/DHF must be viewed on a regional basis. A multidisciplinary approach incorporating region-specific predicted climate changes and nonclimatic factors, such as those listed above, could be used to determine specific regional pathways to successful transmission and, thus, help to identify potential high-risk areas and periods so that appropriate efforts can then be directed at the most effective point to avert or break cycles of transmission.

Recommendations for future research include more regional-scale studies to attempt to identify consistencies in the interactions between dengue/DHF and certain climatic and non-climatic factors, even though their regional combinations and outcomes as regards dengue/DHF incidence may differ. This knowledge would contribute to the construction of more accurate, multilayered and multivariable models to assist in the prediction, control and mitigation of dengue/DHF in areas already severely affected by this disease and also in areas where climate change may herald the unwelcome threat of the emergence of this vector-borne disease.

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Endnotes

1 Dengue fever results from infections with one of four strains, or serotypes, of the dengue virus (DEN-1, -2, -3, -4). DHF, a more acute form of the disease, is initially difficult to distinguish from severe cases of classic dengue (aching bones and muscles, headaches, nausea/vomiting, ocular pain, and bleeding from nose, gums, skin and gastrointestinal organs) but progresses rapidly, with haemorrhaging of blood plasma in the lungs, abdomen and skin, and intense fever; in a third of cases, blood levels decrease to the extent of causing circulatory failure (dengue shock syndrome) (Monath, 1995). Without immediate fluid replacement therapy, death quickly follows. Neurological disorders, convulsions and coma are associated with DHF and dengue shock syndrome.

2 ENSO, a global-scale system of interacting climate fluctuations, is a primary source of interannual variability in weather and climate. El Niño and La Niña, the Pacific signatures of this phenomenon, are in the Western Pacific region respectively associated with drier and wetter than normal conditions.

3 The complete 10-year dataset (1992–2001) provided by the Indonesian Ministry of Health included East Timor (Timor Leste), which gained independence from Indonesia in 1999. As our study investigated patterns of natural phenomena, we did not take into consideration changing political boundaries.

4 According to the Global Historical Climatology Network this range is even smaller at sealevel, with an averaged minimum of just below 26°C (see http://www.ncdc.noaa.gov/oa/climate/research/ghcn/ghcngrid.html#Overview).

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