Socioeconomic determinants of dengue incidence in Singapore

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Abstract

Community participation is critical in sustaining vector population control activities in order to prevent dengue transmission. However, disease exposure in a community is often not uniform across the entire population and the identification of "at-risk" groups would enable the disease prevention effort to be focused and thus cost-effective. We performed ecological data analyses to study the association between socioeconomic variables and dengue incidence in Singapore from 1998 to 2002. Our results indicated that the DF/DHF incidence was ecologically associated with some socioeconomic/demographic characteristics of the population. Areas with a high proportion of socioeconomically disadvantaged residents had also a significantly higher DF/DHF incidence. The *Aedes* population density of larvae was not related to this difference in the DF/DHF incidence, indicating that additional risk factors were present in these population sub-groups, and that dengue control in Singapore could benefit from a more focused effort in outreach to the population of relatively lower socioeconomic levels.

Keywords: Dengue; Socioeconomic; Geographical; Singapore.

Introduction

Dengue fever/dengue haemorrhagic fever (DF/DHF) remains a major health problem in many areas of the world, especially in south-east Asia[1-3]. Much effort has been focused on the prevention and control of dengue infection. The only effective strategy to control a DF/DHF outbreak, in the absence of a vaccine, is to eliminate *Aedes* mosquitoes and its larval breeding habitats[4].

In Singapore, DHF was first recognized as a public health problem during the early 1960s and a nationwide *Aedes* control programme, which incorporated source reduction, public education and law enforcement, was implemented in 1969. The *Aedes* house index (HI) (% of premises positive for *Aedes* breeding) was markedly reduced from more than 25% before 1970 to 1–2% for the entire country since 1982. The significant decline of the DF/

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DHF incidence (about 60 per 100 000 population in 1973 to below 10 per 100 000 in 1982) was the result of an effective *Aedes* surveillance and control programme[5]. Although the *Aedes* mosquito population density has been reduced and maintained to a relatively low level, as indicated by the overall house index, there was a progressive resurgence of DF (but proportionately less DHF) with a periodicity of about 5 to 6 years from 1992 onwards[6-8].

In the last two decades, several studies have investigated the risk factors for DF/DHF in affected communities, including those with poor living conditions, social inequalities and illiteracy[3]. Identified DF/DHF risk factors vary greatly depending on the location, population density, previous exposure to specific serotypes and availability of oviposition sites. Seasonal distribution has also been reported with the *Aedes aegypti* population density and DF/DHF incidence being associated with elevated temperature and rainfall in certain regions[9]. However, not much is known about how socioeconomic or demographic variables could influence the occurrence of DF/DHF in urban centres, such as Singapore. This may have particular importance since DF/DHF outbreaks are likely to initiate from urban centres[10,11]. Geographical correlation analysis may help to answer this question so as to shed some light on providing various perspectives for public health policy-makers when designing control measures for DF/DHF.

The aim of this study was to examine whether or not there was any correlation between socioeconomic/demographic variables and DF/DHF incidence by geographical areas using the Development Guide Plan (DGP) zones in Singapore. Our findings have direct and immediate implications for dengue prevention.

Materials and methods

Units of analysis

The analyses were based on the geographical units, namely, Development Guide Plan areas. The DGP is a detailed urban plan used for each of the 55 planning areas in Singapore designated by the Urban Redevelopment Authority of Singapore, the nation's planning and conservation authority. Each DGP covers a planning area with a population of around 150 000 served by a town centre. In order to obtain stability and reduce sampling variability of disease incidence, 4 DGP areas with less than 10 000 persons (ranging from 1085 to 9403 persons) have been merged with the adjacent zones in our analysis. We also excluded 23 DGP zones from our analyses that are composed of rural areas with very small population size in which no census enumeration was conducted. In addition, only a few cases of dengue (ranging from 0 to 11 cases per year) were notified from these 23 excluded DGP zones during the study period. Hence, only 28 of the DGP groups with enumerated population denominators were included in the final analyses.

Population census

The socioeconomic/demographic (SED) variables by DGP were extracted from the Singapore Population Census 2000 reports[12] and are described in Table 1. The proportions with individual SED characteristics computed for each DGP group were used as SED variables for the analysis.

Data analyses

The residential address of each notified case of DF/DHF was first geo-coded into 28 DGP groups

Table 1: Spearman's rank correlation coefficient (r) between dengue incidence and proportions with individual socioeconomic/demographic characteristics (SED1-18), and average densities of *Aedes aegypti* and *Aedes albopictus* (%) (AED1-2)
[based on 28 Development Guide Plan (DGP) groups in Singapore, 1998–2002]

Socioeconomic/demographic variable (denominator)	r	(p value)
SED1: Landed properties* and others (resident population)	0.645	(0.001)
SED2: Services production industries (working residents aged 15 years and over)	0.592	(0.002)
SED3: 'Other' ethnic group (resident population)	0.560	(0.004)
SED4: Aged 65 years and above (resident population)	0.559	(0.004)
SED5: Non-owner (resident private households)	0.533	(0.007)
SED6: Financial & business services industries (working residents aged 15 years and over)	0.500	(0.010)
SED7: Widowed female (resident population aged 15 years and over)	0.475	(0.014)
SED8: Economically inactive (resident population aged 15 years and over)	0.464	(0.016)
SED9: Attending upper secondary education (resident students aged 5 years and over)	0.453	(0.019)
SED10: Monthly gross income from work below SGD1000 (resident private households)	0.430	(0.026)
SED11: Female Chinese (resident population)	0.429	(0.026)
SED12: No family nucleus** (resident private households)	0.427	(0.027)
SED13: Female living alone (resident population aged 15 years and over)	0.403	(0.037)
AED1: Average density of Ae. aegypti (%)	0.395	(0.040)
SED14: Household size: 8 or above (resident private households)	0.394	(0.041)
SED15: Household size: 1 (resident private households)	0.394	(0.041)
SED16: Attending university education (resident students aged 5 years and over)	0.365	(0.058)
AED2: Average density of Ae. albopictus (%)	0.273	(0.156)
SED17: Indian (resident population)	0.260	(0.177)
SED18: Workers: agriculture & fishery, craftsmen, etc. (working residents aged 15 years and over)	-0.450	(0.019)

* Refers to residents who are living at residential unit with individual ground contact which do not include multi-level apartment buildings. Types of landed properties include bungalow/detached house, linked house, semi-detached, terrace house, town house, and cluster housing, etc. For the latter housing type, it is a hybrid between conventional landed housing and condominium housing and all these units have ground contact but with shared facilities similar to those found in condominiums. Most of these landed property buildings usually are less than 4 floors per building.

** Refers to a household formed by a person living alone or living with others but which does not constitute any family nucleus. Thus it can refer to individuals, but not necessarily to people living alone.

using ArcView software version 9.1 (ESRI, Redlands, CA). Crude DGP-specific DF/DHF annual incidence was calculated based on the total number of cases reported from 1998 to 2002 inclusive, with the person-years denominator being the sum of the annual population estimates for each of the years. The population estimates were obtained by interpolating or extrapolating linear trend of each DGP zone from the Population Census 1990 to the Population Census 2000 to account for population changes over the study period.

Three levels of data analysis, namely, correlation analysis, factor analysis and linear regression analysis, were conducted in this study.

Firstly, the possible geographical correlation between the crude DF/DHF incidence (on log scale) and each SED variable was assessed by using the Spearman's rank correlation coefficient.

Secondly, the potential SED variables identified by the correlation analysis were then summarized into factor scores obtained by using the exploratory factor approach, which examine how underlying constructs influence the response on a number of measured variables[13]. In the factor analysis, the maximum likelihood estimation was used to determine the number of factors to retain, followed by orthogonal (varimax) rotation to assist in the interpretation of the factors and to ensure that the factors were uncorrelated. SED variables with rotated factor loadings (equivalent to Pearson's correlation coefficients between each variable and each factor) having absolute values of 0.6 or greater were used in interpreting the factors and considered "dominant" as the defining SED variables for the identification of specific factors[13]. Scores were computed for rotated factors as the sum of products of observed variables multiplied by their factor loading.

Thirdly, six weighted linear regression models were then used to study the associations between each of the respective factor score-based variables and the DGP group-specific DF/DHF incidence, with or without adjustment for mosquito indices, as a sensitivity analysis (namely, models 1–6 in Figure 1). This analysis allowed for the investigation of the association between the socioeconomic influence and DF/DHF incidence because factor score-based variables minimized the multi-co-linearity problem present in conventional regression analyses. It, therefore, allowed us to obtain a stable estimation. Log-transformation of the DGP group-specific DF/DHF incidence was taken as a dependent variable. The regression was weighted by the DGP group's population size.

The average densities of the two *Aedes* mosquitoes were defined as the total number of *Ae. aegypti* and *Ae. albopictus* larvae observed, divided by the number of premises where larval breeding was found, respectively. These two mosquito variables were also subsequently included together with 2-factors score-based variables in the weighted linear regression analyses.

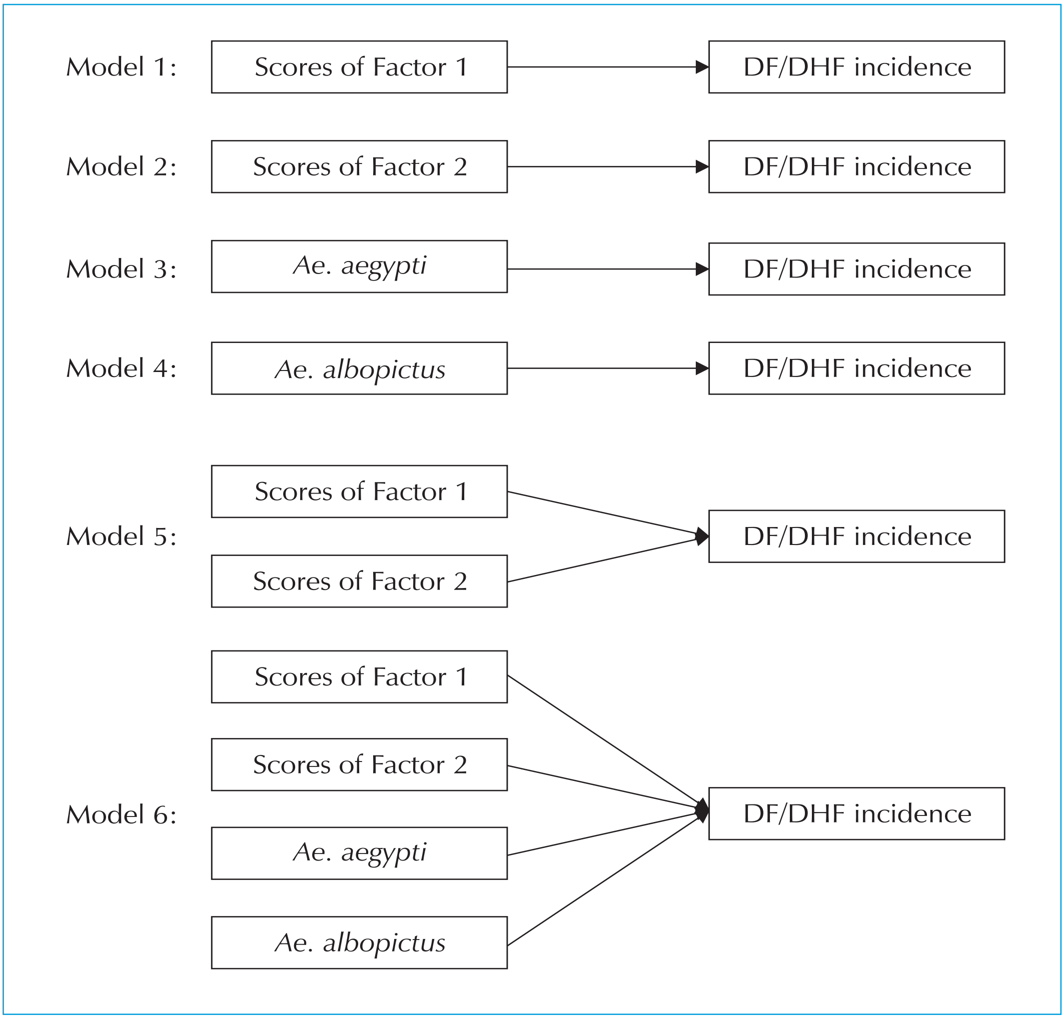
All analyses were performed with S-Plus software version 6.0 (Insightful Corporation, Seattle, Washington) and Stata software version 8.0 (Stata Corporation, College Station, TX, USA).

Results

Geographical variations in DF/DHF incidence

During the study period (1998–2002), there were 16.4 million person-years of observation with 11 888 reported cases of DF/DHF (after excluding 210 cases that occurred in the non-

Figure 1: Schematic diagrams of respective weighted linear regression model used

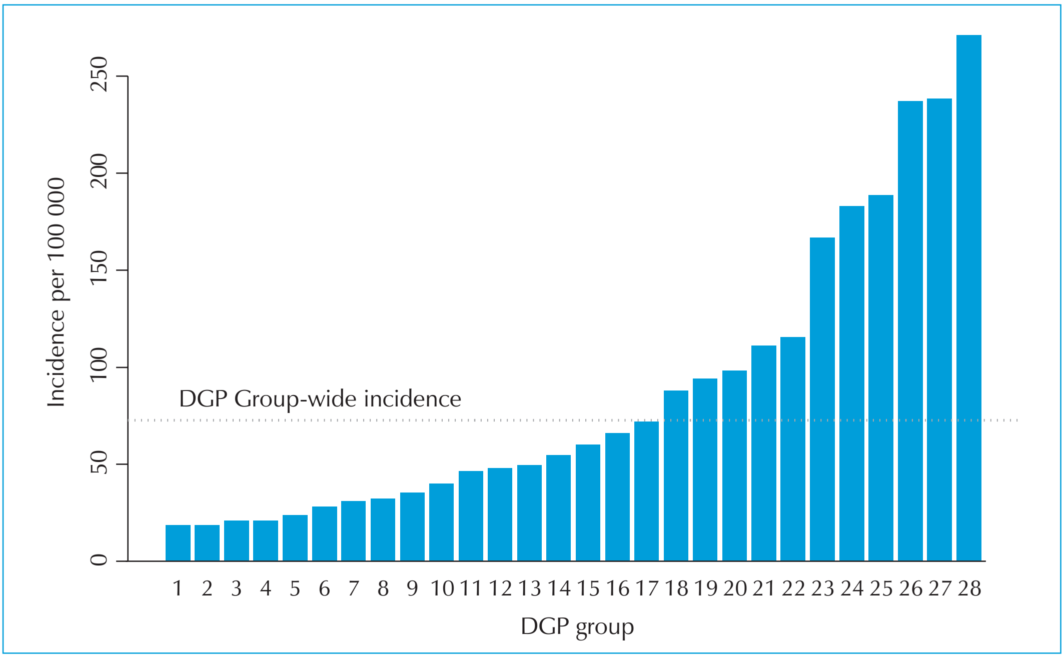


sampled DGP zones). Figure 2 shows the incidence of DF/DHF in each of the 28 DGP groups studied in Singapore. The overall incidence of DF/DHF was 72.7 per 100 000 person-years. The incidence of DF/DHF ranged from 18.8 to 271.2 per 100 000 and all the incidence rates were significantly different ($p<0.01$) from the DGP average, except for two DGP groups (DGP groups 16 and 17) (Figure 2).

Association with socioeconomic/ demographic factors

From the pair-wise ecological correlation analyses (Table 1), the following variables were most significantly associated ($p<0.01$) with the incidence of DF/DHF: landed properties and others ($r=0.65$); services production industries (0.59); and 'other' ethnic group (0.56); aged 65+ (0.56); and non-owner tenancy (0.53).

Figure 2: Incidence rates per 100 000 person-years of dengue fever by Development Guide Plan (DGP) group in Singapore, 1998–2002



In the factor analysis, two factors were extracted based on 16 SED variables that could explain 80% of the total variations (Table 2). The first factor with the first six greatest in absolute value of factor loadings were considered "dominant": low gross monthly income from work (<Singapore dollars, SGD1000), no family nucleus, aged 65+, living alone, female widowed and economically inactive. This is consistent with "retired elderly". Likewise, for the second factor identified had: workers in the business industries, 'other' ethnic group (minority living in Singapore), household size 8 or above, landed property residents, and attending upper secondary school as dominant variables (Table 2). This appears to be consistent with "middle-class adults".

These 2-factors score-based variables were then included in the weighted linear regression analysis. The two indices for the average density of *Aedes* mosquitoes were also included in the regression analysis for further adjustment. Four variables together could explain 32% of the variations ($R^2=0.32$) in the regression model (model 6 in Table 3). However, only scores in the first factor consistent with "retired elderly" remained significantly and positively associated ($p=0.022$) with DF/DHF incidence.

Discussion

Singapore is a modern and highly urbanized tropical island city state with one of the highest urban population densities in the world (6004 residents per square kilometre). In this study, substantial geographical variations in the incidence of DF/DHF were observed, and these variations have been shown to be associated with differences in the socioeconomic/demographic characteristics of the population.

Table 2: Results of factor analysis estimated using maximum likelihood estimation: rotated factors and factor loadings
[based on 28 Development Guide Plan (DGP) groups in Singapore, 1998-2002]

Socioeconomic/demographic variable (denominator)	Factor 1 (Retired elderly)	Factor 2 (Middle-class adults)
SED1: Landed properties and others (resident population)		0.826
SED2: Services production industries (working residents aged 15 years and over)		0.724
SED3: 'Other' ethnic group (resident population)		0.938
SED4: Aged 65 years and above (resident population)	0.962	
SED5: Non-owner (resident private households)	0.906	
SED6: Financial & business services industries (working residents aged 15 years and over)		0.956
SED7: Widowed female (resident population aged 15 years and over)	0.945	
SED8: Economically inactive (resident population aged 15 years and over)	0.904	
SED9: Attending upper secondary education (resident students aged 5 years and over)		0.747
SED10: Monthly gross income from work below SGD1000 (resident private households)	0.995	
SED11: Female Chinese (resident population)		0.622
SED12: No family nucleus (resident private households)	0.963	
SED13: Female living alone (resident population aged 15 years and over)	0.784	
SED14: Household size: 8 or above (resident private households)		0.877
SED15: Household size: 1 (resident private households)	0.938	
SED16: Attending university education (resident students aged 5 years and over)	0.709	
Percentage total variance	46.3%	34.1%
Percentage cumulative variance	46.3%	80.4%

Data are factor loadings, the correlation between the individual variable and each factor. Only variables with loadings ≥ ±0.60 are shown. SED17 and SED18 are not shown because their loadings < ±0.60.

Exploratory factor analysis is a data-reduction statistical method that has been widely used to identify and summarize many inter-relationships that exist among individual variables[13]. In a factor analysis used in this study (schematic diagram shown in Figure 3), inter-correlated variables (variables SED1-16) are grouped into smaller numbers of new variables (2 factors). Such an approach allows for the simplification of the data set analysed in order to gain practically relevant insights into the underlying risk factors and true exposures that are linked to adverse health effects.

Our study had several methodological limitations. Firstly, the actual extent of dengue infection is probably an underestimate since it is based on the notified cases. However, the

Table 3: Summary of multiple linear regression analysis weighted by the DGP group's population size

Model	Variable(s) included in the regression analysis				$R^{2‡}$
	Factor 1* (Retired elderly)	Factor 2* (Middle-class adults)	Average density of *Ae. aegypti* (%)	Average density of *Ae. albopictus* (%)	
	Reg. Coef.† (p value)	Reg. Coef.† (p value)	Reg. Coef.† (p value)	Reg. Coef.† (p value)	
Model 1: DF/DHF incidence = Scores of Factor 1	0.391 (0.015)	–	–	–	20.7%
Model 2: DF/DHF incidence = Scores of Factor 2	–	0.313 (0.145)	–	–	8.0%
Model 3: DF/DHF incidence = Av. density of *Ae. aegypti* %	–	–	0.041 (0.075)	–	11.7%
Model 4: DF/DHF incidence = Av. density of *Ae. albopictus* %	–	–	–	0.035 (0.126)	8.8%
Model 5: DF/DHF incidence = Scores of Factor 1 + Scores of Factor 2	0.383 (0.015)	0.293 (0.132)	–	–	27.7%
Model 6: DF/DHF incidence = Scores of Factor 1 + Scores of Factor 2 + Av. density of *Ae. aegypti* % + Av. density of *Ae. albopictus* %	0.399 (0.022)	0.092 (0.724)	0.036 (0.256)	–0.007 (0.785)	32.0%

* Scores of Factor 1 and Factor 2 obtained from factor analysis and socioeconomic variables contributed to each factor referred to in Table 2.

† Regression coefficient estimated from weighted linear regression.

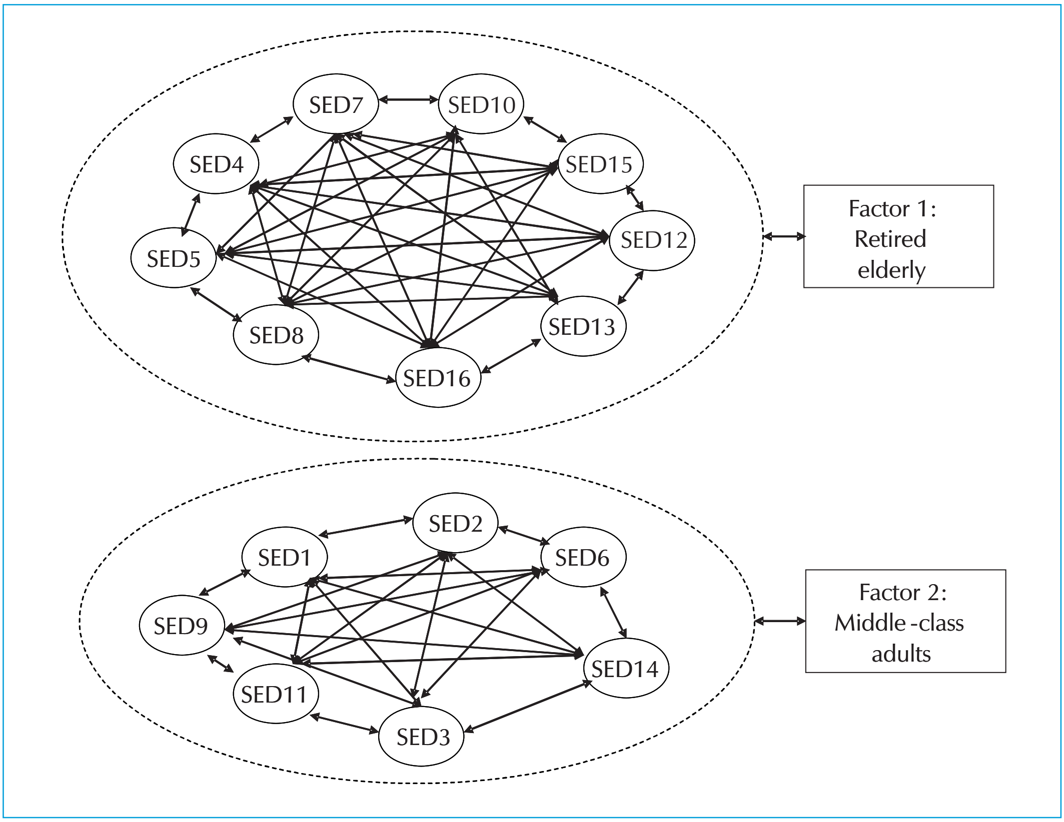
‡ R-squared interpreted as percentage of variation explained by respective model.

proportion of sub-clinical to clinical cases may not be as high as previously reported[14] in Singapore since almost 90% of the total cases happen in adults[7,15]. If this discount factor occurred randomly across all geographical areas, the magnitude of ecological correlation analyses based on relative geographical variations would only tend to bias toward the null[16]. In addition, regarding the size and choice of a geographical unit, a recent study showed that for a given time point and deprivation score, the deprivation gap in crude survival was some 25 times smaller when estimated with larger geographical units than with small ones. This suggests that our estimates are conservative[17].

Secondly, like other dengue-endemic countries, the DF/DHF incidence may be affected by various environmental factors, such as rainfall, humidity and temperature. A local study showed that these meteorological conditions preceded the DF/DHF incidence by 8–20 weeks[18]. While there may be differences in such environmental factors in different parts of Singapore, these may not be significant given the very small geographical size of the island. Furthermore, as the DF/DHF incidence was aggregated over a 5-year period in our analysis, the short- and medium-term fluctuations of meteorological conditions are less likely to have an impact on our analysis.

Thirdly, the association between socioeconomic/demographic factors and DF/DHF incidence was assessed based on ecological data. Therefore, as with any ecological analysis, interpretation of these findings must be done with caution. Individual-

Figure 3: Schematic diagram showing inter-correlated variables (please see variables socioeconomic/demographic variables: SED1-16 in Table 1) grouped into smaller numbers of new variables (2 uncorrelated factors: retired elderly and middle-class adults) using data-reduction statistical method, factor analysis



based studies are needed to validate the hypothesis generated from these findings[19].

In a cancer study conducted in Thailand, the socio-demographic characteristics that influenced the decision-making of the patient's caretaker to receive alternative therapy included the level of education, occupation, residential areas and lay symptom assessment[20]. For the economic factors, the capability to reimburse the cost of treatment, the family income and the financial resources were also important[20]. In our study, the DF/DHF incidence was ecologically associated with some socioeconomic/demographic characteristics of the population, such as those with low income (economically inactive; Spearman's r=0.46 or monthly gross income from work below SGD1000; 0.43), living alone (household size 1; 0.39), gender (female living alone; 0.40 or widowed female; 0.48), and less attention paid to environmental hygiene (aged 65+; 0.56, no family nucleus; 0.43, household size 1; 0.39, and widowed female; 0.48), a group we have collectively referred to as "retired elderly". In such a population group, the *Aedes* larval breeding sites in the domestic and peri-domestic environment could increase due to poor hygiene[21] and failure to check for breeding and reluctance to have their homes fogged with insecticide[22]. In addition, non-owner tenancy householders (r=0.53) could be less responsible in cleaning up their premises. Living in landed properties was also associated with a higher DF/DHF incidence (r=0.65) as it has been consistently observed that there are more breeding habitats in these premises[5].

We found that areas with a high proportion of socioeconomically disadvantaged residents have significantly higher incidence rates of DF/DHF. *Ae. aegypti* and *Ae. albopictus* population densities, taken individually without the inclusion of other factors, are insufficient to account for the observed difference in the DF/DHF incidence rates (Models 3 and 4 in Table 3). It is interesting to note that in the same multivariable regression analysis, the regression coefficient of the average density of *Ae. albopictus* on DF/DHF incidence was significantly reduced (regression coefficients: 0.035 in Model 4 vs –0.007 in Model 6), but the *Ae. aegypti* variable had less reduction although both variables did not reach statistical significance (regression coefficients: 0.041 in Model 3 vs 0.036 in Model 6, Table 3). This suggests that *Ae. aegypti* remains the principal vector for dengue virus transmission, despite the greater abundance of *Ae. albopictus*.

Because this finding is based on ecological data, we cannot conclude that persons from poor families have a higher risk of DF/DHF without further prospective studies. However, it is consistent with the hypothesis that susceptibility to infection is associated with low socioeconomic status[23]. The higher DF/DHF incidence in the socioeconomically disadvantaged residents could also likely be due to socio-behavioral barriers in seeking health care[24,25] or some other behavioural or environmental processes operating at household or individual levels that supported breeding of *Aedes* mosquitoes (e.g. monthly gross income from work below SGD1000 was correlated with average densities of *Ae. aegypti*, r=0.703, data not shown) and transmission of dengue viruses[26].

Until a safe and effective vaccine is available, controlling *Aedes* mosquitoes, active laboratory-based case as well as entomological surveillance[27,28], and improved case management are the principal options available for reducing the burden of DF/DHF in Singapore. More cost-effective integrated control measures such as public health educational campaign targeting 'hot-spot' areas, in which both DF/DHF incidence and factor scores are high, could be a logical approach to minimize the impact of the disease[26-30]. [The 'high-high' areas defined as the first one-third of the DGP groups with high DF/DHF incidence accounted for 28.3% of the total annual cases but only 10.4% of the total population size, and the first one-third of the factor scores (data not shown)].

In conclusion, the results of this study suggest that dengue control in Singapore could benefit with a more focused effort in outreach to the population in relatively lower socioeconomic regions. Further efforts should be directed at addressing the barriers to behavioural change, correcting misconception on the spread of dengue by social and close contact, and educating them and the illiterate on measures to prevent dengue[22].

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