Am. J. Trop. Med. Hyg., 32(1), 1983, pp. 170–174

RELATIONSHIP BETWEEN NUMBER OF HUMAN JAPANESE ENCEPHALITIS CASES AND SUMMER METEOROLOGICAL CONDITIONS IN NAGASAKI, JAPAN

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Abstract. Analysis of epidemiological and meteorological data for Nagasaki Prefecture, southwest Japan, for the period 1950–1979, showed a correlation between size of epidemics of human Japanese encephalitis (JE) and weather factors. It was demonstrated that during the period 1950–1969 the epidemic size (ES) had two types of correlation: ES correlated inversely with total summer precipitation, and ES correlated directly with mean summer temperature. The fact that in the 1970s there were fewer cases of JE cannot be attributed to changes in the weather factors. Large epidemics occurred in summers with low precipitation and high temperatures, while the epidemic size was small when there was heavy precipitation and temperatures were low. The two weather factors jointly explain 0.53 of the observed variance in annual JE ES. Furthermore, they strongly correlate with each other, and total summer precipitation alone is sufficient to explain about one-half of the total variance. How these factors influence the number of JE cases is discussed in relation to the population dynamics of the vector mosquito, *Culex tritaeniorhynchus*.

Epidemiologists concerned with the prevention of Japanese encephalitis (JE) have long suggested positive correlations between the number of JE cases and weather conditions. Local health authorities in endemic areas warn the public in early summer of the possibility of a JE epidemic if the local meteorological agency forecasts a hot summer. This is because it has been commonly believed that hot summers result in large epidemics of JE due to heightened reproductive activities of the vector mosquito, *Culex tritaeniorhynchus*, on the one hand, and higher infection and morbidity rates among people who have become more susceptible due to fatigue, on the other. However, whether or not prediction of an epidemic on these grounds has validity has never been examined from a statistical point of view.

It has been reported that in the Nagasaki area, southwest Japan, summer precipitation and temperature are the dominant factors which determine the yearly abundance of *Cx. tritaeniorhynchus* breeding in rice fields.[1] Population growth of this species starts after rice plants have been transplanted into wet paddies at the end of June, and the population begins to diminish in mid-August when the plants have become tall and thick. Weather conditions during this period, therefore, have a profound influence on the level of peak mosquito abundance at the end of July or beginning of August. What follows is a statistical examination of the relationship between the number of JE cases among people in Nagasaki Prefecture and its summer weather conditions.

MATERIALS AND METHODS

The data used range over the 30-year period from 1950–1979. JE cases are taken from the statistics kept at the Nagasaki Prefectural Office. They are not serologically confirmed cases but only "alleged" ones based solely on clinical symptoms; some non-JE cases are no doubt included. At the present time, however, reported cases are the only available piece of information for the epidemiological analysis of JE cases over a long period of time; confirmation by serological tests commenced only in 1964. The total number of reported cases for 1964–1979 was 367, of which 316 were submitted to serological tests and 169 (about 53%) were confirmed. During these years there was a high correlation between the number of reported cases and that of confirmed ones ($r = 0.97$; $P < 0.001$). As the population in Nagasaki Prefecture has remained at about 165×10^4 during the 30-year period, the actual number of cases can be a good indicator for the epidemic intensity.

The meterological data were taken from those observed and kept at the Nagasaki Marine Ob-

Accepted 28 May 1982.

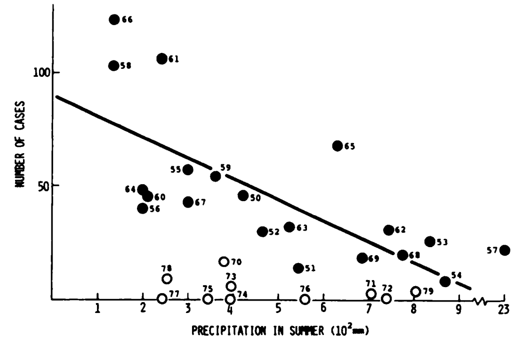

FIGURE 1. Relation between number of Japanese encephalitis cases and summer precipitation, Nagasaki Prefecture, 1950–1979. Solid circles are for 1950–1969, open circles for 1970–1979; numeral by circle represents year. Precipitation is the total for 21 June to 10 August. Precipitation for 1957 (2,309 mm) was excluded in calculation of the regression equation.

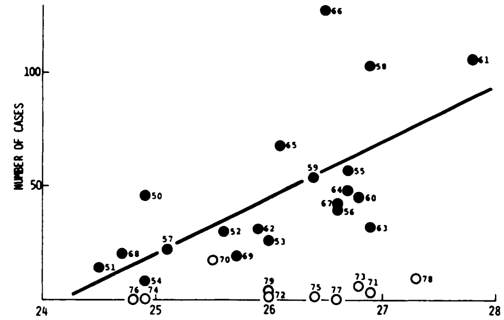

FIGURE 2. Relation between number of Japanese encephalitis cases and summer temperature, Nagasaki Prefecture, 1950–1969. Solid circles are for 1950–1969, open circles for 1970–1979; numeral by circle represents year. Summer temperature is a mean for the period 21 June–August 10.

servatory located in Nagasaki City. A preliminary examination indicates a close direct correlation between the Observatory's data and those at other weather stations distributed over the prefecture. Summer precipitation in this study is taken to mean the total precipitation from 21 June to 10 August, inclusive. The average temperature in summer is represented by the mean, for the same period, given by daily mean temperatures based on six observations at 4-hour intervals.

RESULTS

Figures 1 and 2 represent summer weather conditions and numbers of human JE cases in Nagasaki Prefecture for the period 1950–1979. It is clear that the overall epidemic level in the 1970s was much lower than it was in the 1950s and 60s. During the period 1950–1969, there were some cases each summer and the yearly average was about 47. During the 1970s, however, the average was reduced to about four cases per year, and in 2 of the 10 years no cases were reported. This sharp drop in the epidemic level cannot be explained by some change in the two climatic factors alone. The range of distribution of both precipitation and temperature during the 1970s was about the same as it was during the 1950s and 60s, the only exception being the year 1957 in which a very high level of precipitation was recorded. Since the JE epidemic data for the 1970s are too small in number for statistical analysis, only the period 1950–1969 is analyzed in what follows.

As can be seen in Figure 1, there was a clear inverse correlation between precipitation and the number of cases over the two decades. Low precipitation accompanied large outbreaks of JE; the three largest epidemics, with 127 (1966), 196 (1961), and 103 (1958) cases, respectively, all occurred when precipitation was less than 300 mm. Two of them, in particular, happened during the driest summers when precipitation was only 134 and 136 mm, respectively. In contrast, during wet summers with precipitation of 700 mm or more only 30 or fewer cases were reported.

There was also a marked tendency for large outbreaks of JE to occur in hot summers (Fig. 2). The largest epidemics, with 100 cases or more, were exclusively during those years in which average temperature exceeded 26°C. Conversely, there were less than 50 cases when the average temperature was below 26°C.

The two weather variables correlated inversely with each other, as can be seen in Figure 3. A typical rainy summer in southwest Japan is brought about when the subtropical air mass on the Pacific is weak relative to the subpolar one on the continent, and the polar front does not move to the high latitude region as quickly as in most years. This prolonged rainy season is inevitably accompanied by a cold summer, when temperature rise by radiant heat, furthermore, remains minimal.

Table 1 summarizes the interrelations among the three variables, i.e., number of cases (y), precipitation (x_1), and temperature (x_2). The univariate regression equations and the correlation coefficients (r) are all highly significant. The value r^2

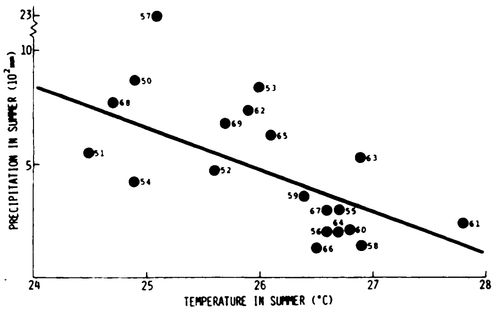

FIGURE 3. Relation between precipitation and temperature in summer, Nagasaki Prefecture, 1950–1969; numeral by circle represents year. Precipition of 2,309 mm in 1957 is excluded from calculation of the regression equation.

denotes the proportion of the observed variance in dependent variables which can be explained by the calculated regression equation. Thus, precipitation alone explains 0.48 of the observed variance in numbers of cases, while temperature alone explains 0.41. Precipitation, therefore, is the better variable of the two with which to predict the number of human JE cases.

The multivariate regression equation including the two weather factors as predictor variables, and the coefficient of multiple correlation ($R = 0.73$) also were highly significant, as is seen in Table 1. This means that the null hypothesis

$$b_1 = b_2 = 0 \tag{1}$$

can be rejected, where b_1 represents the partial regression coefficient on x_1 and b_2 that on x_2. The actual values for b_1 and b_2 are −0.0629 and 11.9, respectively. Significance test for these coefficients indicates that b_1 is significant but b_2 is not (Table 2: only $b_1 = 0$ in (1) is rejected and not $b_2 = 0$). In other words, when x_1 is adopted as a predictor variable, it is unnecessary to add x_2 as there can be little independent role of x_2 in prediction. This

TABLE 2

Significance tests of partial regression coefficients of the multivariate regression equation

Predictor variable	Partial regression coefficient with 95% confidential limit	Significance*
Summer precipitation	-0.0629 ± 0.0650	$P < 0.01$
Summer temperature	11.9 ± 17.6	$P > 0.10$

* By t-test.

conclusion is in line with the fact that R^2 (0.53) is not distinctly larger than r^2 between precipitation and the number of cases (0.48).

DISCUSSION

Significant correlation has been demonstrated between the number of human JE cases and the two weather factors, i.e., total precipitation and mean temperature in summer. These factors jointly explain 0.53 of the variance in yearly numbers of cases during the period 1950–1969. However, they are strongly correlated with each other and multivariate analysis indicates that precipitation alone is sufficient to explain the combined effect of the two on the number of JE cases. In view of the multiple factors involved in the determination of the level of JE epidemics,[2] this contribution rate of precipitation is considered very high. It can be said with certainty that outbreaks of human JE occurred in the Nagasaki area much more frequently in summers with low precipitation and high temperature than in those with heavy precipitation and low temperature.

There have been no other reports which demonstrate as clearly the high correlation between the number of human JE cases and the weather factor. Part of the success of this study is attributable to the appropriateness of the selection of a season for analysis. The 50-day period from late June through early August was arrived at through

TABLE 1

Correlations among summer precipitation (x_1), summer temperature (x_2), and number of human Japanese encephalitis cases (y)

Regression equation	r or R	r^2 or R^2	Significance*
$y = 89.6 - 0.0911x_1$	−0.69	0.48	$P < 0.01$
$y = -589.7 + 24.4x_2$	0.64	0.41	$P < 0.01$
$x_1 = 5275.4 - 184.7x_2$	−0.66	0.44	$P < 0.01$
$y = -236.4 - 0.0629x_1 + 11.9x_2$	0.73	0.53	$P < 0.01$

* By F-test.

an earlier population study on the vector mosquito which showed that precipitation and temperature during this period are dominant factors in determining the yearly peak abundance of the vector in midsummer.[1] Local vector ecology, therefore, should be studied before an appropriate season is selected for similar analysis in other areas.

The sharp drop in the number of JE cases in the 1970s is not attributable to some change in such climatic conditions as precipitation or temperature. As suggested by many Japanese epidemiologists, this decline must have resulted primarily from lowered population levels of the vector mosquito, *Cx. tritaeniorhynchus,* breeding in rice fields. A remarkable decrease in levels of population of this mosquito was recognized throughout Japan in about the year 1970. For example, in Kyoto, central Japan, the average population level fell as low as one-hundredth of that of the 1960s.[3] It has been postulated that the decline is the result of the combined influence of changes in the rice cultivation and rural environment, the most important of these being the change in the kinds of insecticides and herbicides sprayed over rice fields to control rice pests and weeds, which took place around 1970. Chemicals being used now are more effective than those used earlier in killing mosquito larvae, and they are less toxic to their natural enemies such as fish and spiders. Widespread administration of vaccination against JE virus must also have played a role in lowering the morbidity rate among the exposed population.

The combination of low precipitation and high temperature can influence the epidemic level in a number of ways; it may actually work in part in favor of reduction of epidemic size. Low humidity and high temperature, for instance, reduce the survival rate of adult mosquitoes, thereby tending to lower the possibility of infection. What the result of the present study demonstrates, however, is that that part of the effect of low precipitation and high temperature which works towards expansion of epidemic size outweighs that part which works against it. The following are likely to comprise the major processes that contribute towards an epidemic of JE. First of all, high temperature accelerates multiplication of the causative virus in the vector mosquitoes.[4] Second, low precipitation and high temperature bring about an increase in the vector population since the survival rate of immature mosquitoes is heightened through a shortened developmental period. The mean daily temperature of surface water exposed to direct sunlight becomes higher than the mean atmospheric temperature by 3–4°C on the average and about 8°C at the maximum.[1] It is expected, therefore, that the mean temperature at the surface of open and shallow water collections such as Japanese rice fields is several degrees higher in a hot sunny summer than in a cold rainy one. If, for example, the larval-pupal period is reduced from 11 days to 7, the emergence rate will jump from 2–8% under a constant daily survival rate of 70%,[5] which quadruples the number of emerging adults. Third, low precipitation minimizes the loss of aquatic stages due to water currents; this loss is estimated to be considerable in a rainy summer.[6] With the highly developed irrigation system in Japan, water supply to rice plants is secured for at least 1 month after transplantation in early summer even under the conditions occurring during the direst summer encountered in a 30-year period. Consequently, it is rare for a decrease in mosquito breeding places to result from low precipitation during the period following transplanting.

Review of the literature indicates that urban outbreaks of St. Louis encephalitis transmitted by the *Culex pipiens* complex in the United States tend to occur in dry hot summers, sometimes after a rainy spring.[7] This situation may be similar to that of JE in Nagasaki. On the other hand, in California significant correlation has been found between the rate of annual river flow and the *Culex tarsalis* population which transmits western equine encephalitis and St. Louis encephalitis.[8] In the latter study, heavy rains were considered to have increased the area of breeding places for the vector mosquito. The type of correlation between weather conditions and the number of human cases of mosquito-borne disease can be expected to vary according to vector species and local ecological conditions.

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Dr. Norio Yamamura, Mr. Nobuyuki Tsuji, and Miss Terumi Senju, Saga Medical School, for valuable aid in the statistical analysis and calculation, and Mr. Reizo Matsuo, Nagasaki Prefectural Institute of Public Health, for aid in utilizing the statistics regarding JE cases. He is also grateful to Drs. Yoshito Wada, Mitsuo Takahashi and Akira Oya, National Institute of Health, for reviewing the manuscript. Dr. M. Takahashi further helped him to read the literature. Finally, the author thanks Dr. Kensuke Tokaichi, Saga Medical School, for assistance with the English language.

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