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THE INFLUENCE OF CLIMATE ON THE SEASONAL PREVALENCE OF PLAGUE IN THE REPUBLIC OF VIETNAM

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Abstract: An 8 year study of the influence of climate on the seasonal prevalence of bubonic plague in the Republic of Vietnam has been completed. Climatic conditions were found to influence the course of plague epidemics in 2 ways: 1) by regulating the density of the flea population; and, 2) by regulating the efficiency of *Xenopsylla cheopis* in transmitting the plague bacillus. Slight variations in temperature, relative humidity, and vapor pressure deficits either permit an epidemic to flourish or cause a decline in its intensity.

INTRODUCTION

The seasonal prevalence of bubonic plague has been studied to relate plague seasons to climate and provide a basis for forecasting the plague potential of a given area.[4,5,10,11,16,26,29] Brooks[4] and Rogers[26] defined the meteorological conditions that appeared to influence the course of epidemics. In general, seasonal declines observed in epidemics were believed to be the result of adverse effects of climate on the various stages of the flea life cycle. Further study, however, demonstrated that there was inadequate information on all of the variables involved and that the subject of forecasting should be allowed to rest until these variables were better understood.[5,11] With the general decline of plague outbreaks throughout the world, little recent attention has been given to the subject.

In 1962, however, a rather large outbreak of bubonic plague occurred in the Republic of Vietnam (RVN). The seasonal prevalence of the disease, which reappeared year after year in the same locales, assumed some importance in the planning of control programs. Accordingly, a study was initiated to gather the requisite data. While for obvious reasons some aspects of the study could not be as complete as was desired, other facets of the epidemiology of plague in RVN simplified some of the factors which required consideration. The majority of plague cases that occur throughout the country are of the flea-borne bubonic form.[7,8,9] The major, if not the only, flea vector involved in the cities of RVN, where the majority of the cases occur, is *Xenopsylla cheopis*.[7,8,9,17,18] As the most important vector of the plague bacillus on a world-wide scale, the bionomics of *X. cheopis* have received intensive study. The *X. cheopis* in RVN are resistant to DDT.[7,8,9] For the period covered by this report, DDT was the only insecticide available for control. Therefore, for all practical purposes, the effects of the control program were minimal.[9] In general, all of the cases were associated with the same mammalian reservoirs, *Rattus norvegicus, R. rattus, R. exulans,* and *Suncus murinus*.[7,8,9,17,18] As demonstrated by Haas,[12] considerations that must be devoted to microclimate are minimal: occupied rodent burrows in the tropics are warmer than the surrounding environment due to the body heat of the occupant; and, the reliative humidity is greater, often approaching saturation, due to

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the unconscious water loss through respiration by the rodent occupant.

In analyzing the data presented in this report, two possible effects of climate upon the course of the epidemic were considered: 1) influence upon the density of the flea population; and 2) influence upon the efficiency of *X. cheopis* in transmitting the plague bacillus. Knülle[15] found that relative humidity values in excess of 65% are required for the proper development of *X. cheopis* larvae. Although adult *X. cheopis* are considered to be less sensitive to dry air,[2,3,20] exposure of adult fleas to air with a vapor pressure deficit of over 7.62 mm Hg results in a decreased life span of adult fleas when temperatures approximate 30 C.[1] This reduction in life span, however, is not such that it would result in fleas dying before they had time to become biological vectors and transmit the agent.[6,13,14] Extreme humidity is also harmful, air approaching saturation has adverse effects on the flea life cycle.[2,3,28] It is also well documented that temperatures in excess of 27.5 C decrease the vector efficiency of *X. cheopis*.[6,13,14,19,23,24] Mechanisms resulting in decreased vector efficiency of *X. cheopis* involve enzymatic reactions and therefore proceed at enzymatic rates varying with temperatures. This phenomena results in a situation where many fleas operating at low vector efficiency rates could maintain an epidemic at the same level as that achieved by fewer fleas operating at maximal efficiency.[6] RVN lies in the hot, wet tropics and is subject to two monsoon seasons. Further, a great portion of the country is mountainous: topography modifies climate to a great extent. Therefore, in view of the considerations outlined above, it appeared mandatory to evaluate the epidemiology of plague in RVN on a regional basis.

The results of the study indicate that the forecasting of plague outbreaks is exceedingly complex and requires extensive investigation and knowledge of quite circumscribed locales. The observations which led us to this conclusion form the basis of this report.

OBSERVATIONS

For the purposes of this study, RVN was subdivided into three general regions, the Mekong Delta, the coastal lowlands, and the central highlands. Locales in these regions which have experienced more or less continual infection since 1962 are listed in Table 1. Sharp seasonal

TABLE 1. Geographical regions in the Republic of Vietnam and locales within those regions that experience annual epidemics of bubonic plague.

Region	Locale	Elevation meters	Temperature annual range °C	Precipitation annual average Cm	Average no. plague cases per year	Peak month
Mekong Delta	Saigon	8.8	25.7 - 29.1*	224	91	Apr
			24.3 - 29.2**	180	11	
Coastal Lowlands	Phan Thiet	9.9	24.4 - 28.1	101	203	Mar
	Nhatrang	5.0	23.8 - 28.6	129	223	Mar
	Qui Nhon	4.8	22.8 - 29.8	160	1049	Mar
	Quang Ngai	8.3	21.6 - 29.0	243	509	Apr
	Danang	5.8	21.7 - 29.6	197	604	Apr
	Hue	16.0	19.4 - 29.9	260	420	Apr
Central Highlands	Ban me Thuot	537.0	20.0 - 25.0	169	619	Feb
	Pleiku	800.0	19.1 - 23.4	207	37	Apr
	Dalat	1500.0	19.1 - 22.2	172	37	May

* Epidemic year
** Endemic year

peaks in the prevalence of bubonic plague are observed in all of these locales with the exceptions of Dalat and Pleiku where plague occurs more or less continually. Epidemic peaks occur later in the year as one proceeds north along the coast of RVN or as elevation increases in the central highlands, perhaps reflecting a requirement for warmer temperatures in the mountains. The majority of cases occur in the northern ⅔ of the coastal lowlands, whereas relatively few cases occur south of 12°. Saigon may or may not experience an epidemic of bubonic plague during a given year.

Survey data obtained in a city in each of these three regions illustrate the epidemiology of plague in the region and the probable influence of climate. Tables 2-5 list data for the cities of Saigon,

TABLE 2. Relationship of climatic conditions to the prevalence of bubonic plague and fleas in the city of Saigon (epidemic year).

Month*	Precipitation (Cm)	Relative humidity % (VPD)**	Flea index	% Plague cases	Temperature °C
1	Tr	79.0 (5)	0.53	0	27.4
2	Tr	74.1 (7)	0.94	0	27.0
3	0.2	70.5 (7)	2.05	0	24.3
4	7.8	69.7 (8)	5.17	2	26.8
5	25.7	68.5 (8)	5.70	29	27.2
6	26.5	68.9 (9)	4.02	44	29.2
7	20.6	78.2 (6)	3.03	16	28.1
8	32.2	81.0 (5)	1.82	8	27.4
9	33.1	80.0 (6)	1.99	1	27.5
10	23.2	81.9 (5)	1.12	0	27.3
11	6.3	86.3 (4)	1.12	0	26.6
12	4.4	82.3 (5)	1.49	0	27.2

* Data adjusted so that the 6th month is the month of peak prevalence for bubonic plague epidemic.
** VPD = Vapor pressure (mm Hg) deficits calculated temperature to the nearest degree and relative humidities to the nearest 5%.
Tr = trace

TABLE 3. Relationship of climatic conditions to the prevalence of bubonic plague and fleas in the city of Saigon (endemic year).

Month*	Precipitation (Cm)	Relative humidity % (VPD)**	Flea index	% Plague cases	Temperature °C
1	1.8	80.5 (5)	1.04	10	26.4
2	Tr	76.1 (5)	1.05	3	25.9
3	2.6	69.3 (8)	1.21	0	25.7
4	9.7	65.5 (10)	1.30	0	27.0
5	25.9	68.9 (9)	2.95	9	27.9
6	38.0	71.0 (9)	3.85	26	29.1
7	38.9	80.0 (6)	2.81	3	28.2
8	41.5	80.4 (6)	2.46	12	27.9
9	28.9	81.7 (5)	1.12	3	27.4
10	25.1	83.6 (5)	1.59	0	27.1
11	15.3	82.9 (5)	0.72	31	27.1
12	5.0	84.0 (4)	1.19	3	26.8

* Data adjusted so that the 6th month is the month of peak prevalence for bubonic plague epidemic.
** VPD = Vapor pressure (mm Hg) deficits calculated temperature to the nearest degree and relative humidities to the nearest 5%.
Tr = trace

Nhatrang, and Pleiku. For purposes of comparison, the data were treated as follows: The data were assembled on a monthly basis. The percentage of the total number of plague cases that occurred during a given month was calculated as were the mean monthly values for temperature, relative humidity, vapor pressure deficit and precipitation. The data were then tabulated so that the month of peak plague prevalence was shown as the 6th month. Thus, the data pertaining to the events preceding the peak of the epidemic are shown as those

TABLE 4. Relationship of climatic conditions to the prevalence of bubonic plague and fleas in the city of Nhatrang.

Month*	Precipitation (Cm)	Relative humidity % (VPD)**	Flea index	% Plague cases	Temperature °C
1	24.9	83.5 (4)	6.43	4	26.3
2	30.9	83.4 (4)	ND	6	25.2
3	27.7	80.4 (5)	4.81	13	24.4
4	5.4	76.4 (6)	ND	8	23.9
5	1.6	77.6 (5)	ND	10	24.6
6	2.1	79.1 (5)	6.55	22	25.8
7	4.9	80.2 (5)	8.48	18	27.2
8	9.3	80.7 (5)	7.14	9	28.2
9	2.2	77.9 (6)	ND	3	28.2
10	2.3	78.4 (6)	5.72	2	28.1
11	4.6	78.3 (6)	ND	2	28.0
12	12.6	81.4 (6)	ND	3	27.0

* Data adjusted so that the 6th month is the month of peak prevalence for bubonic plague epidemic.
** VPD = Vapor pressure (mm Hg) deficits calculated temperature to the nearest degree and relative humidities to the nearest 5%.
ND = No data.

TABLE 5. Relationship of climatic conditions to the prevalence of bubonic plague and fleas in the city of Pleiku.

Month*	Precipitation (Cm)	Relative humidity % (VPD)**	Flea index[22]	% Plague cases	Temperature °C
1	5.7	83.1 (3)	ND	5	20.7
2	2.0	80.2 (4)	0.70	5	19.5
3	1.0	77.2 (4)	0.13	7	19.1
4	7.1	74.7 (4)	0.98	3	19.9
5	3.3	71.9 (6)	1.70	8	22.8
6	11.6	76.4 (5)	5.50	30	23.5
7	32.4	85.2 (3)	1.77	7	23.4
8	27.4	89.3 (2)	1.10	8	22.9
9	39.7	91.4 (2)	0.19	13	22.4
10	39.7	92.8 (1)	0.04	7	22.1
11	27.6	90.7 (2)	0.03	2	21.9
12	9.6	85.9 (3)	ND	5	21.5

* Data adjusted so that the 6th month is the month of peak prevalence for bubonic plague epidemic.
** VPD = Vapor pressure (mm Hg) deficits calculated temperature to the nearest degree and relative humidities to the nearest 5%.
ND = No data.

for the months 1 through 5 and the events corresponding to the decline of the epidemic are shown as those for the months 7 through 12. This method permits direct comparisons from locale to locale. In view of the uncertainty of a plague epidemic occurring in Saigon during a given year, the relevant data for this city are presented in two tables. Table 2 presents data for a year in which an epidemic was observed in Saigon and Table 3 presents the corresponding data for 3 years in which the disease was endemic, but not epidemic in the city.

The extent of plague infection in the rat population of Saigon is not as great as it is in Nhatrang and is reflected in the fact that many more cases of plague occur in Nhatrang than in Saigon. Despite the fact that rodent plague epizootics occur simultaneously with human epidemics and with comparable intensity in both Nhatrang and Saigon, conditions for flea transmission in Saigon appear marginal. As measured by the prevalence of *Pasteurella pestis (Yersinia pestis)* antibodies in rat sera, only 3.53% of the 4,889 rats examined in Saigon demonstrated plague antibody in contrast to 21.36% of 529 rats tested in Nhatrang, Table 6. The isolation rate for *P. pestis* from rats is approximately 10 times greater in Nhatrang, while the isolation rate from fleas is approximately 20 times greater.

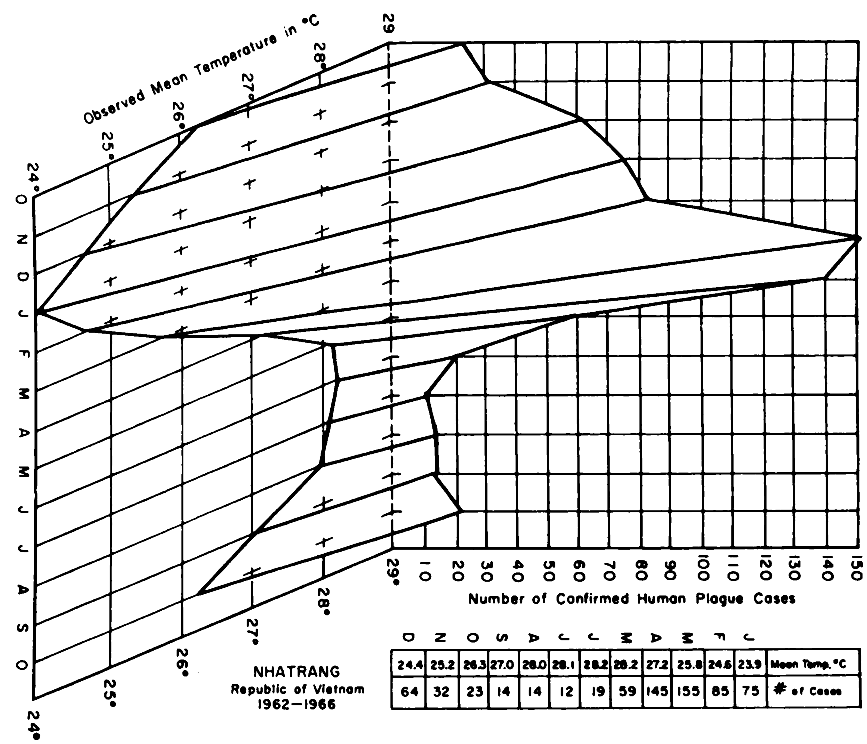
In Nhatrang the flea index during the first 2 months of the decline in the human epidemic exceeded the flea index of the peak month of the epidemic. The relative humidity and vapor deficits remained essentially unchanged. The mean monthly temperature continued to increase reaching the critical range. As the temperature exceeded 27.2 C, there was a shift in the epidemic curve as reflected by a slight reduction in the incidence of human plague. A further increase in the mean temperature to 28.2 C coincided with a 60% reduction in human cases. During the following 3 months when mean temperature exceeded 28 C, the number of human cases continued to decline to the annual low. With a drop in mean monthly temperature to 26.3 C, the epidemic curve again shifted direction, as reflected by steadily increasing numbers of human cases. The case rate/temperature relationship is shown in Figure 1.

When the area of consideration was expanded to include the entire coastal lowland region, the relationship of the epidemic to the various climatic factors was more pronounced, as shown in Figure 2. As the rains declined, the epidemic commenced, went through its normal cycle, and then regressed several months prior to the onset of the next rainy season. Vapor pressure deficits did not exceed the critical value, 7.62 mm Hg, until some months after the peak of the epidemic. As in Nhatrang, a marked decline in the epidemic was observed as temperatures exceeded 27.9 C.

TABLE 6. Incidence of plague infection in commensal mammals in Nhatrang and Saigon.

	P. pestis antibody in *R. norvegicus* sera			*P. pestis* isolations from commensal mammals	
City	No. sera tested	No.sera with antibody*	% sera with antibody*	Rat tissue pools	Flea pools
Saigon (Endemic area)					
Epidemic year	2275	74	3.3	3	6
Endemic year	2614	99	3.8	9	2
Nhatrang (Epidemic area)	529	113	21.36	10	16

* HA titer of 1/32 or greater.



D	N	O	S	A	J	J	M	A	M	F	J	
24.4	25.2	26.3	27.0	28.0	28.1	28.2	28.2	27.2	25.8	24.6	23.9	Mean Temp. °C
64	32	23	14	14	12	19	59	145	155	85	75	# of Cases

FIGURE 1. Relationship between the monthly plague morbidity rate and the mean monthly temperature in the city of Nhatrang for the years 1962-1966.

DISCUSSION

Disregarding the number of susceptible human beings and rodents present in an area, the impression is gained that the epidemiology of bubonic plague is under the natural control of the climate to be found in any particular focus. The variables that must interact in a complex manner to complement each other are temperature, precipitation, and atmospheric humidity. Of the individual variables, temperature is probably of the greatest controlling importance in that: 1) temperature regulates the rate of metamorphosis of *X. cheopis* from egg to adult;[1] 2) temperature governs relative humidity and the degree of humidity in ambient air at a given temperature determines the vapor pressure deficit which is a measure of the drying power of the air; and 3) temperature regulates the vector efficiency of *X. cheopis*. Factors 1 and 2 govern the density of the flea populations and factor 3 governs the duration and intensity of the outbreak when adequate numbers of *X. cheopis* are present.

Precipitation is also a controlling influence. Early in these studies when the Republic of Vietnam was being treated as a single geographic unit, a negative correlation between rainfall and plague epidemics was reported.[7,8,21,22] The influence of precipitation on the flea population is probably adverse. *X. cheopis* is a

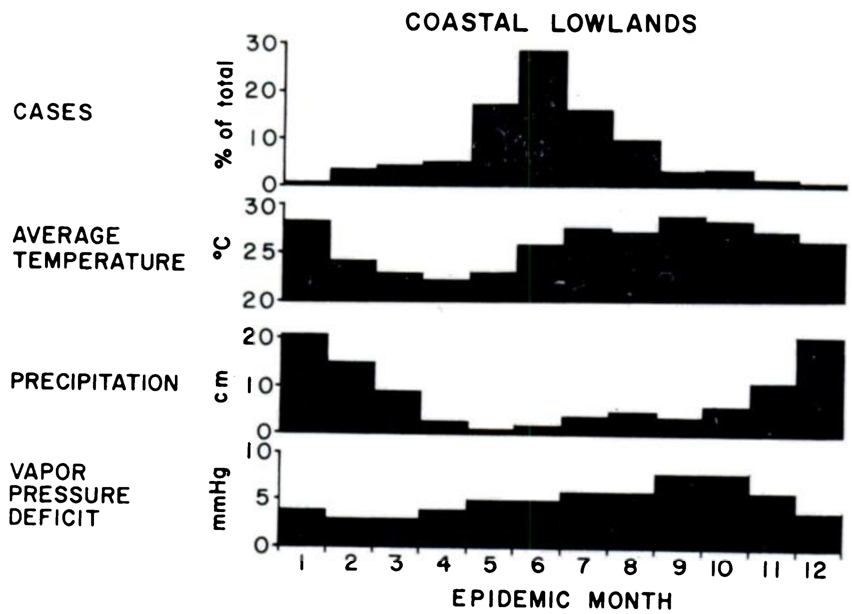


FIGURE 2. Relationship between the occurrence of plague and various climatic factors in the coastal lowlands of the Republic of Vietnam 1962-1966.

ground dwelling flea[25] and the single story construction typical of the plague foci in RVN is such that most fleas must originate from nests on the ground floors or in burrows. RVN receives abundant precipitation during the year. One cm of rainfall is equivalent to 16.38 cubic meters of water falling on 1 hectare of surface area (about 10,691 gallons per acre). In areas where drains are absent, or where drainage is inadequate due to soil composition or impoundment of water in rice paddies, flooding undoubtedly causes a reduction in the flea population. In areas with better drainage, such as those with sandy soils along the coastal lowlands, reduction of the flea population due to flooding may be minimal. One other effect of rainfall is that of briefly increasing the number of plague infections resulting from a concentration of rodents, fleas and humans in the same shelter. Whatever effect precipitation may have on the flea population, it is not of sufficient influence in Saigon to cause a decline in the plague epidemic which continues through several months of rather heavy rain. A rising flea index was even observed in a period of heavy rainfall in Saigon during the corresponding months of the years when the disease was not epidemic. While the plague season in Nhatrang occurs during the dry season, rainfall does not appear to have an adverse effect on the flea population. In Pleiku, the onset of seasonal rain coincides with both a decline in the incidence of human disease and a reduction of the flea population.

In contrast to the lack of a general correlation between epidemic, flea index and rainfall, an excellent relationship between relative humidity, vapor pressure deficit and flea index exists. In Nhatrang where the relative humidity does not fall below 75% and the vapor pressure deficit does not rise above 6 mm Hg, it appears that the environment never becomes too dry for *X. cheopis* in this city. In Pleiku, however, the ambient air may be too moist at the period when fleas are reduced in numbers. The heavy rains that relate to the decline of the epidemic also result in an increased saturation of the atmosphere and a corresponding reduction in the drying power of the air. Since an even greater degree of saturation of the air in occupied rodent burrows occurs in the tropics,[12] conditions in the nests and burrows may be too damp for optimal production of *X. cheopis*. In Saigon, during the years when plague was not epidemic, the relative humidity dropped to 65.5% in a month when the epidemic would normally gather velocity. The air was also very dry, the vapor pressure deficit reaching a value of 10 mm Hg in the same month. The flea index was low at a critical period and the flea population did not recover until the expected epidemic season was nearly over. During the same critical months of the year in which plague was epidemic, the relative humidity was a little higher, the drying power of thé air was not as great, and a relatively higher flea population was present.

Temperatures in excess of 27.5 C reduce the efficiency of *X. cheopis* in its ability to transmit the plague bacillus.[6,13,14,19,23,24] This effect of temeprature was clearly demonstrated. In Pleiku where the temperature never approached 27.5 C, the peak plague season coincided with the peak annual temperature. In the coastal lowland, in general, and Nhatrang, in particular, when the mean monthly temperature exceeded 27.5 C, the annual plague epidemics were observed to decline. Upon the termination of the hot season, a gradual increase in the monthly incidence of human disease to epidemic proportions was again observed.

Unlike Nhatrang where plague epidemics occur annually, Saigon has experienced but a single small epidemic during the observation period. In contrast to the areas in the northern ⅔ of RVN, the peak of the Saigon epidemic occurred during a period when temperatures were unfavorable. During the ensuing endemic years in which an average of but 11 cases per year occurred, the temperatures were even more adverse. As shown in Table 6, the incidence of plague infection in the rat population measured by both the prevalence of plague antibody and the isolation of *P. pestis* from rat tissues was greater in the endemic period. However, *P. pestis* was isolated with 3 times greater frequency from fleas during the epidemic year.

The complex interactions of the variables involved suggest that the evaluation of a given locale for its plague potential should be based on careful study of available records and the results of survey data rather than on generalities. As discussed above, small variations in temperature, relative humidity, and vapor presusre deficit have a significant effect on the course of a plague epidemic. Realizing the fact that topography modifies climate to a considerable extent, the subject of forecasting the plague potential for a given locale requires a careful evaluation of available records and survey data for that locale. In areas such as Saigon, where conditions for plague epidemics are at best marginal, year by year evaluations may be required as plague may persist for long periods of time in the rodent population without the disease becoming epidemic. As discussed in a companion paper,[27] other mechanisms than fleas exist to maintain plague in an enzootic form in the rat population. It is evident that, in such areas, the persistence of plague under adverse circumstances provides seed for epidemics when more favorable conditions are achieved. Plague foci deserve careful study to evaluate the periodicity of epidemics so that logistic requirements for control can be anticipated.

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