

LXXXIV. THE INFLUENCE OF SATURATION DEFICIENCY
AND OF TEMPERATURE ON THE COURSE OF EPIDEMIC
PLAGUE.

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(With 18 Charts.)

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THE prompt decline of plague epidemics in Northern India with the onset of the hot weather led many observers to the conclusion that the establishment of a critical temperature was the most important factor in checking the course of the infection. The facts concerning the seasonal prevalence of plague in six selected places in India were examined by the Plague Commission (1) and the conclusion was arrived at "that a plague epidemic is checked when the mean daily temperature passes above 80° F. and especially when it reaches to 85° F., or 90° F." The fact that at high temperatures the plague bacillus disappears from the stomach of the flea more rapidly than at lower temperatures has been suggested as a possible explanation.

The question was subsequently investigated by the Commission (2) and (3) with special reference to Belgaum and Poona, localities in which plague epidemics tended to decline under presumably favourable conditions of temperature, and it was shown that variations in atmospheric humidity had an important relation to the seasonal prevalence of the disease and that variations in the percentage humidity of the atmosphere were associated with variations in the average number of fleas found per rat at different times of the year.

The relative humidity figures of a locality do not, however, give precise information as to the drying capacity of the air at the temperature in question, and it was thought that if from the percentage humidity and temperature figures, "saturation deficiency" figures were derived, these might afford more useful information for the analysis of plague data in the light of atmospheric conditions. By "saturation deficiency" is meant the difference between the actual tension of aqueous vapour present in the atmosphere at the temperature in

question and the tension of aqueous vapour that would be present in a saturated atmosphere at the same temperature.

The importance of expressing the hygrometric condition of the atmosphere in terms of saturation deficiency will be readily apparent if it be remembered that dry air at 50° F. has actually a smaller saturation deficiency, and hence a smaller drying capacity, than 80 per cent. saturated air at 100° F.; the saturation deficiency in the former case being .360 of an inch, in the latter case .384 of an inch.

The Commission has collected and correlated data for plague deaths and the temperature and percentage saturation of the atmosphere for a number of localities in India during the past few years. From these figures I have calculated the saturation deficiencies and replotted them in relation to plague deaths. The data for a number of localities not studied by the Commission have also been treated in the same way. By expressing the facts in this way the possible influence of variations in dryness and variations in mean temperature on the incidence and course of epidemic plague in India can be separately studied and how far the influence of the former may be exercised independently of the factor of temperature.

It has been pointed out by Greenwood (5) that the factors that cut a plague epidemic short are more determinate than those responsible for its commencement. The decline of plague in a locality doubtless may depend on circumstances other than climatic, for in isolated outbreaks in the same district the epidemic subsides in one village at the same time that it is developing in another. Nevertheless, the seasonal incidence of the disease in India is one of the characteristics of plague epidemiology.

From the examination of a large number of charts plotted to show (a) the mean monthly temperature, (b) the mean monthly saturation deficiency, and (c) the percentage above and below the mean of the monthly plague deaths for the locality, or the average monthly deaths for five plague years, it is quite apparent that in a considerable number of cases as soon as the mean temperature rises above 80° F., the epidemic rapidly declines. In most localities, however, a rise of temperature is associated with a corresponding increase in saturation deficiency, so that in these cases it is impossible to assess the importance of temperature and dryness. It is only by the study of the climatic conditions in a number of regions that the differential effect becomes manifest.

The cutting short of the epidemic at a temperature at or above 80° F. is, in all those cases I have been able to investigate, associated with a

saturation deficiency of $\cdot30$ of an inch or upwards, and this association is so constant that it seems quite reasonable to suppose that there is a real and critical relation between the two figures in so far as either of them have effect in checking epidemic plague. The chart of Bombay (see Chart I) gives a good example of this association, the epidemic curve falling rapidly as soon as the temperature passes 80° F.; the saturation deficiency remaining at or about the $\cdot30$ of an inch mark for some time. The mean temperature remains at about 80° F. until the month of November, but from the month of June onwards the saturation deficiency is not unfavourable to plague, and indeed autumn recrudescences of plague in Bombay are by no means uncommon. The charts of Lahore (see Chart II) and Lucknow (Chart III) are very similar and may be

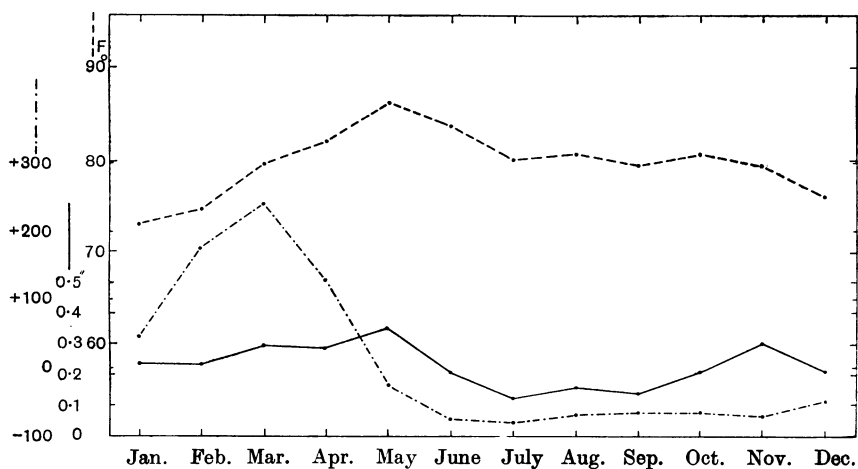


Chart I. Bombay.

- Temperature.
- Saturation deficiency.
- · - · - Plague deaths. (Average above and below the mean for years 1896-1904.)

cited as other examples of the epidemic being checked by the rising of the mean temperature to over 80° F., though in these cases the saturation deficiency is considerably higher than $\cdot30$ of an inch at that temperature. At the time the saturation deficiency reaches $\cdot30$ of an inch in these localities the mean temperature is under 70° F., and at this temperature such a degree of deficiency does not appear to be sufficient to influence the course of the epidemic. The charts of Ballia (see Chart IV) and Darbhanga (see Chart V) afford additional examples of

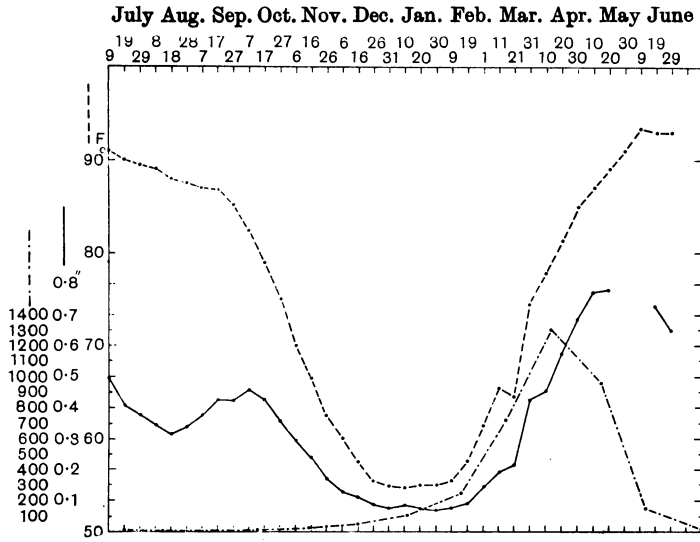


Chart II. Lahore.

- Temperature.
- Saturation deficiency.
- Plague deaths. (5 years' average.)

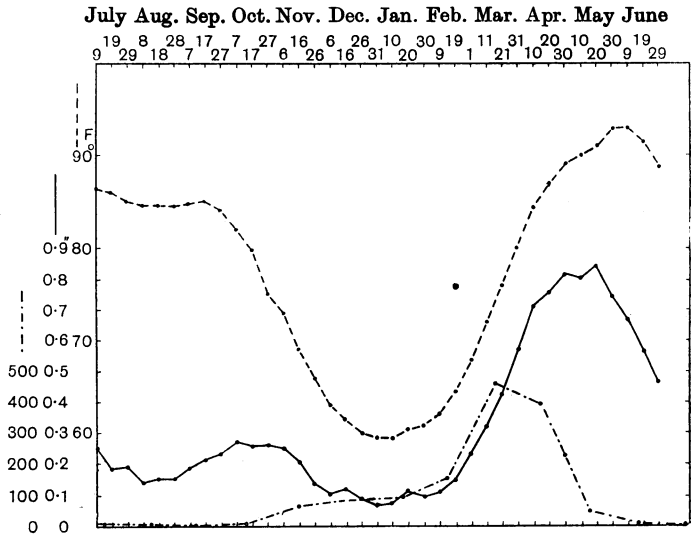


Chart III. Lucknow.

- Temperature.
- Saturation deficiency.
- Plague deaths. (5 years' average.)

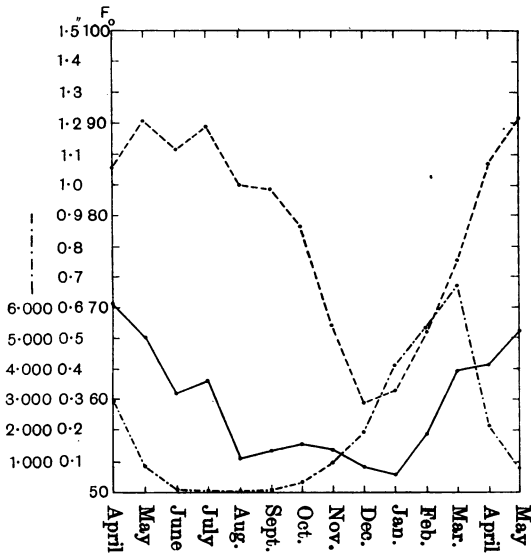


Chart IV. Balia. April 1911—May 1912.

--- Temperature.
 — Saturation deficiency.
 - - - Plague deaths.

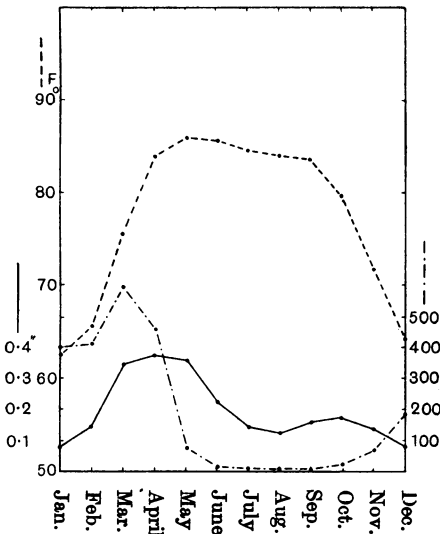


Chart V. Darbhanga.

--- Temperature.
 — Saturation deficiency.
 - - - Plague deaths. (5 years' average)

886 *Influence of Saturation Deficiency and Temperature*

a falling epidemic associated with a rising temperature and saturation deficiency.

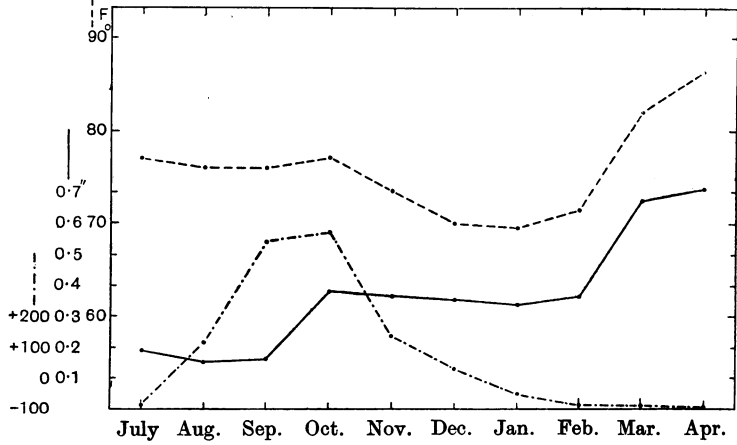


Chart VI. Poona. Early plague years 1897-8, 1900-1 and 1906-7.

----- Temperature.
 ——— Saturation deficiency.
 - - - - - Plague cases. (Average above and below mean.)

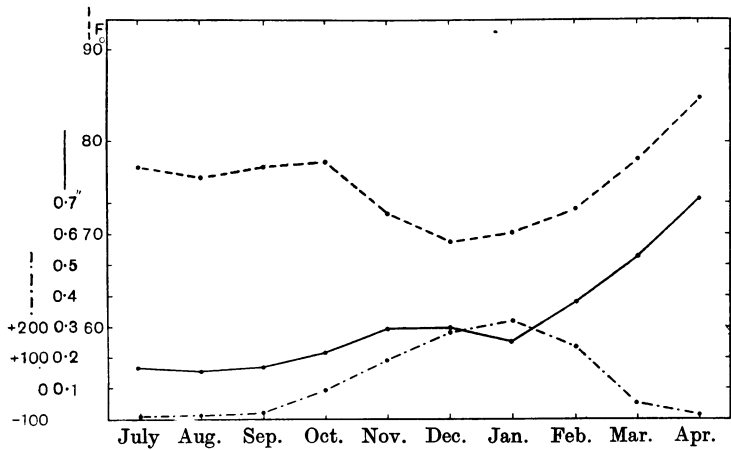


Chart VII. Late plague years 1901-2, 1902-3, 1903-4 and 1904-5.

----- Temperature.
 ——— Saturation deficiency.
 - - - - - Plague deaths. (Average above and below mean.)

If, however, an appropriate degree of saturation deficiency be present, the epidemic may decline long before the mean temperature

reaches 80° F. and may indeed be practically over before that event occurs.

In this connection an examination of the epidemics in Poona is of peculiar interest, as in this locality the usual epidemics may be divided into two groups, (a) a group in which the outbreak occurs between August and November, and (b) a group in which the epidemic season is roughly November to February. The two accompanying charts (see Charts VI and VII) are plotted out from the average figures for three years of early epidemics (1897–1898, 1900–1901, 1906–1907) and for four years of late epidemics (1901–1902, 1902–1903, 1903–1904, 1904–1905) respectively. It will be seen that in both charts the mean temperature does not reach 80° F. until the epidemic season is over, so that, as already pointed out by the Commission, the cutting short of the Poona epidemics cannot be due to the effect of temperature *per se*.

It will however be observed that in the group of early epidemics the saturation deficiency rises to nearly .4 of an inch in the month of October, coincident with the falling of the epidemic, and is associated with a mean temperature of 77° F. A study of the group in which the epidemic is of late occurrence, reveals quite a different state of affairs, for here the saturation deficiency does not rise above .30 of an inch until the month of February, and this increase of the saturation deficiency is again correlated with the decline of the epidemics. The two charts reveal practically the same mean temperature conditions month for month throughout the year, so that were it not for the fact that there is no apparent explanation why the epidemics in 1901–2, 1902–3, and 1904–5 should have been delayed in *onset*, the conclusion that saturation deficiency is in each case responsible for the decline of the epidemic would be irresistible.

The chart of Nagpur (Chart VIII) during the epidemic of 1903–1904 presents another example suggesting the effect of a rapid rise of saturation deficiency abruptly terminating a plague epidemic at a mean temperature considerably below 80° F. The epidemic commenced under favourable conditions of temperature and saturation deficiency in September, rose to its height in December–January and then rapidly fell with the increasing saturation deficiency. In the month of February the saturation deficiency had risen to .44 of an inch, while the temperature was but 74° F. The epidemic was at that time rapidly declining, and by the time the temperature reached 80° F. the saturation deficiency was nearing .60 of an inch and the epidemic was practically

at an end. When the deficiency was at $\cdot30$ of an inch the epidemic was still raging, the temperature being about 70° F., whence it appears that a saturation deficiency that is instrumental in checking plague at 80° F. is not sufficient to have the same effect at a lower range of temperature (70° F.).

The chart of Jhansi in the Bundelkhand district of the United Provinces (Chart IX) shows a similar condition of affairs. The curves are plotted to show the course of the epidemic of 1911–1912, with the temperatures and saturation deficiencies for the epidemic period.

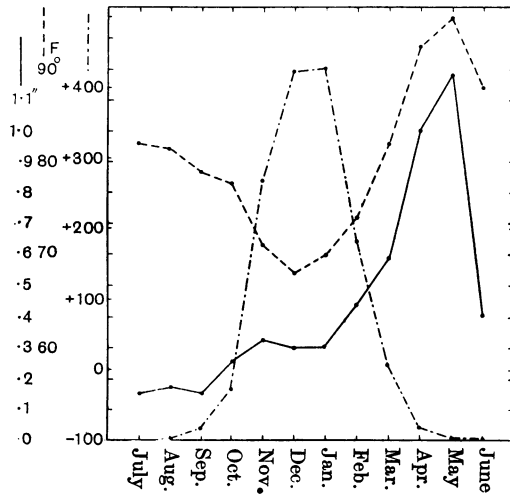


Chart VIII. Nagpur. Epidemic of 1903-4.

- Temperature.
- Saturation deficiency.
- Plague deaths. (Average above and below mean.)

During most of the year the high temperature and high saturation deficiency were quite unfavourable for the occurrence of epidemic plague. The first plague cases occurred in the month of November, when conditions became favourable, and the height of the epidemic was reached in February, when the temperature was about 70° F. and the saturation deficiency about $\cdot30$ of an inch. The epidemic declined very rapidly, *pari passu* with a sudden rise in the saturation deficiency, and by the middle of March was well under way; the temperature at that time being only 76° F. but associated with a saturation deficiency of $\cdot67$ of an inch.

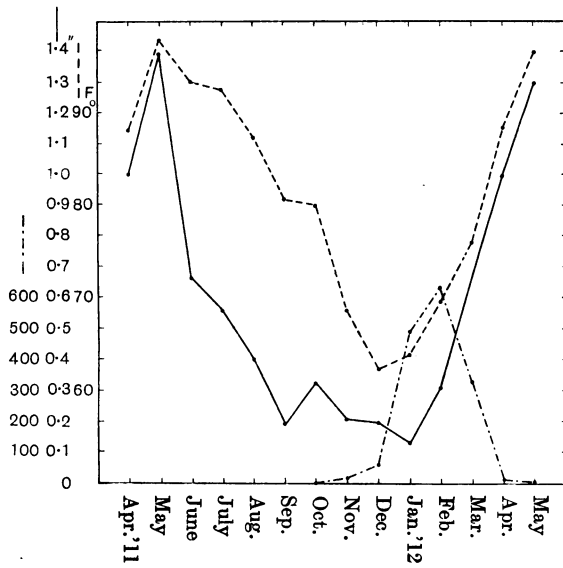


Chart IX. Jhansi. April 1911—May 1912.

----- Temperature.
 ——— Saturation deficiency
 Plague deaths.

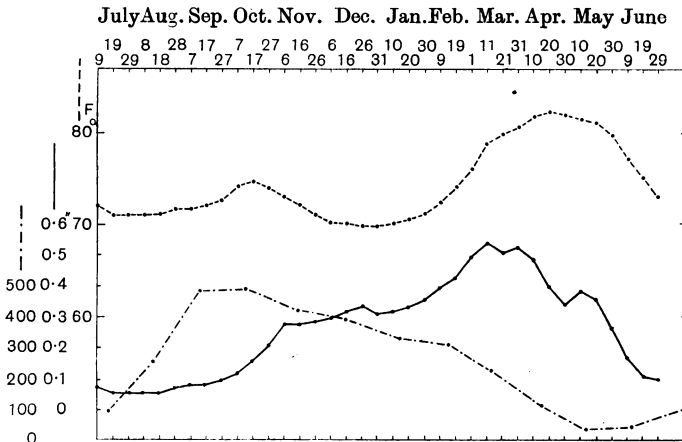


Chart X. Belgaum.

----- Temperature.
 ——— Saturation deficiency.
 Plague deaths. (Average of 5 years.)

890 *Influence of Saturation Deficiency and Temperature*

The chart of Belgaum (Chart X) again shows the epidemic declining under favourable conditions of temperature but unfavourable conditions of saturation deficiency for such temperature. By the time the temperature has reached 80° F., the saturation deficiency has reached $\cdot 50$ of an inch and the epidemic has practically spent itself. Belgaum was at no time absolutely free from plague, but during the months of April and May, when the conditions are the most adverse, the mortality is comparatively slight.

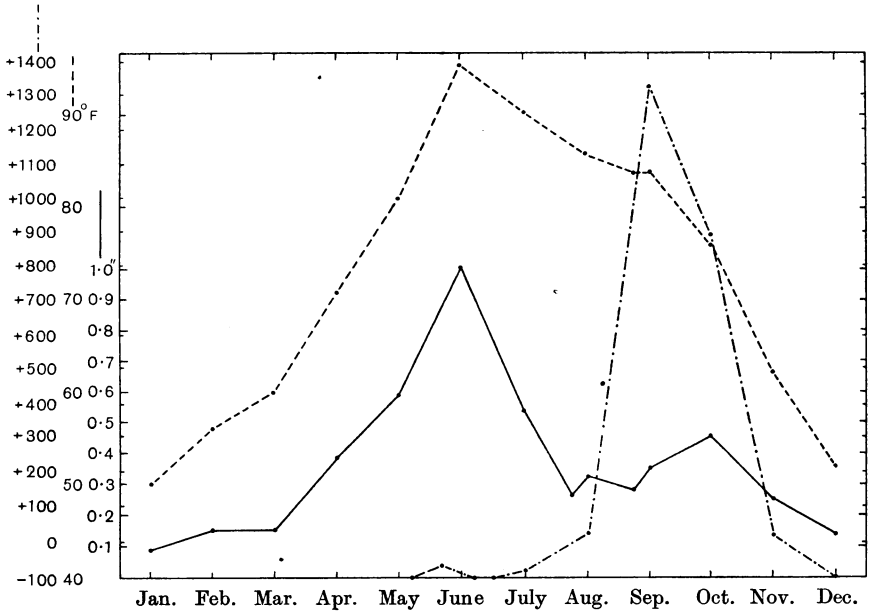


Chart XI. Rawalpindi. First epidemic, 1903.

- Temperature.
- Saturation deficiency.
- · - · - Plague deaths. (Average above and below mean.)

The influence of the saturation deficiency on the commencement of the epidemic.

If an examination be made of all the charts previously referred to, it will be seen that the epidemic season for plague started, in all cases, when the mean temperature was well below 80° F. As previously pointed out, in India this temperature is usually associated with a saturation deficiency of $\cdot 30$ of an inch or upwards, and in such conditions

it does not appear that plague can assume epidemic proportions. When, however, a temperature of 80° F. and upwards is associated with a low saturation deficiency, plague may become epidemic in spite of a high mean temperature. The chart of Rawalpindi (Chart XI), showing the first plague epidemic there, which occurred in the year 1903, reveals this interesting state of affairs. The disease, which was apparently slumbering during the hot and dry weather, suddenly assumed epidemic proportions in August-September 1903. Coincident with the rise of the epidemic the saturation deficiency fell in the early days of August to .26 of an inch, having somewhat abruptly fallen from so high a

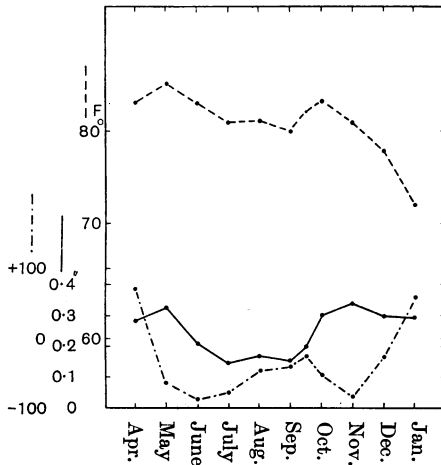


Chart XII. Autumn recrudescence of plague in Bombay, Aug.-Sept. 1898.

- Temperature.
- Saturation deficiency.
- Plague deaths. (Average above and below mean.)

deficiency as 1.07 of an inch since the middle of June. The temperature meanwhile had been steadily falling from 92° F., which it had attained in the month of June, but was still at the 84° F. mark when the epidemic was at its height in September. The epidemic then rapidly declined, as the saturation deficiency rose to .45 of an inch in the month of October, the mean temperature *falling* meanwhile to 76° F.

An examination of plague data in connection with the port of Bombay reveals the fact that there the epidemic season reaches its height in March or April. It has, however, been observed that in some years slight recrudescences occur in the months of August and

892 *Influence of Saturation Deficiency and Temperature*

September. So far as I am aware no satisfactory explanation has yet been given with regard to these "autumn epidemics."

During the period in question the temperature is usually above 80° F. and to that extent would not unreasonably be considered as unfavourable to recrudescent plague. An examination of the chart (see Chart XII) of the autumn recrudescence of 1898 shows clearly that during the whole period under consideration the mean temperature never fell below 80° F., but that the rise in the plague curve was associated with a very low degree of saturation deficiency. As the

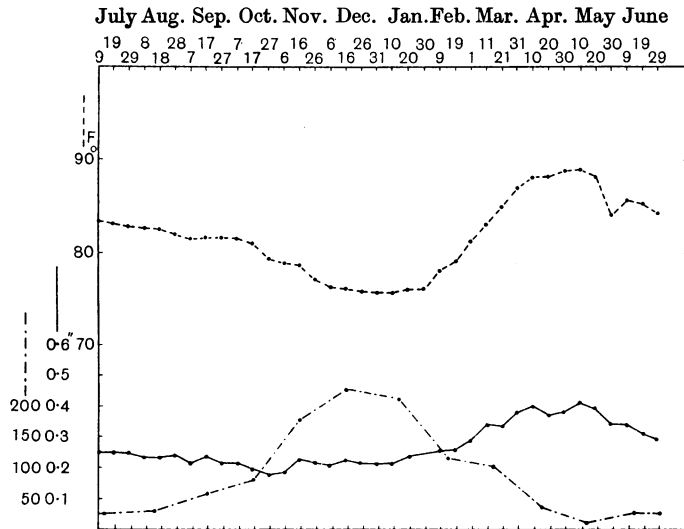


Chart XIII. Salem.

- Temperature.
- Saturation deficiency.
- · - · - Plague deaths. (Average of 5 years.)

saturation deficiency approached $\cdot 30$ of an inch with the mean temperature over 83° F., the number of plague cases rapidly fell. In November the temperature dropped to below 80° F. with the saturation deficiency remaining about $\cdot 30$ of an inch and plague again resumed epidemic proportions. The chart of Salem (see Chart XIII) reveals the same state of affairs, though to a less marked degree than is the case of Rawalpindi. Plague occurs here at all months in the year but reaches its lowest level during the comparatively hot and dry months of April, May and June. In the month of July the saturation deficiency

falls below $\cdot30$ of an inch, while the temperature is still above 80° F. This state of affairs continues till about the middle of October, the number of plague cases rising steadily the while. The plague incidence is considerably increased as soon as the temperature falls below 80° F.; the saturation deficiency remaining at about $\cdot20$ of an inch.

The climatic conditions met with in Rangoon, Burma, are quite different from those which obtain in India proper, and are of peculiar interest in an investigation of the present nature. It will be observed (see Chart XIV) that for nine months in the year the mean temperature is above 80° F., falling at no time, during the remaining three months,

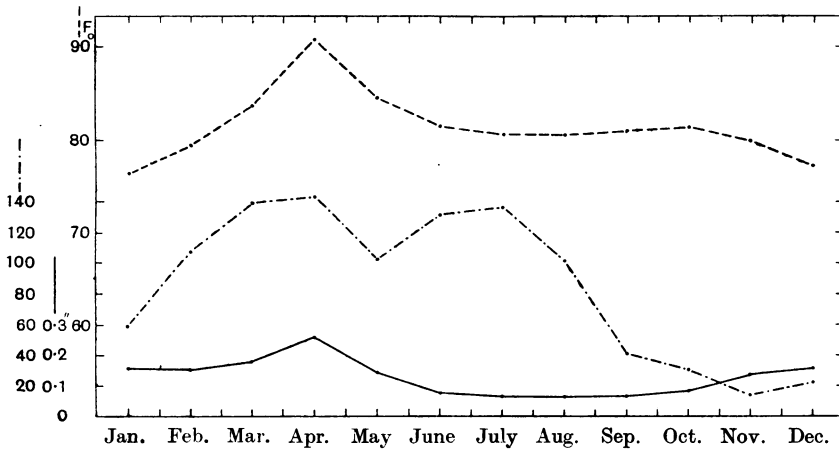


Chart XIV. Rangoon.

- Temperature.
- _____ Saturation deficiency.
- · - · - Plague deaths. (Average of 5 years.)

below 76° F. During the month of April the mean temperature rises to over 87° F., at a time, be it observed, when the plague mortality is at its highest. The saturation deficiency throughout the year is, however, exceptionally low, varying between the limits $\cdot06$ and $\cdot26$ of an inch. In Rangoon, in spite of the high mean temperature throughout the year, the saturation deficiency is exceptionally low, and judging from experience elsewhere it cannot be said that there is any season of the year at which the climatic conditions are unfavourable for the development of plague. It is true that the number of cases of plague during the months October to December are comparatively

few, but as the climatic conditions at this time of the year are by no means antagonistic to the maintenance of epidemic plague, an explanation of the reduction in the case incidence and mortality from this disease during these months must be due to other causes.

An examination of charts derived from particulars given by Van Loghem and Swellengrebel (6) with regard to plague in Java, Dutch East Indies, is interesting and instructive. The first chart (see Chart XV) shows the incidence of plague in the Melang Department of Java, from its introduction in April 1911 to October 1912. Although the time of the east monsoon is spoken of as the "dry period" and the time of the west monsoon as the "wet period," there is extraordinarily

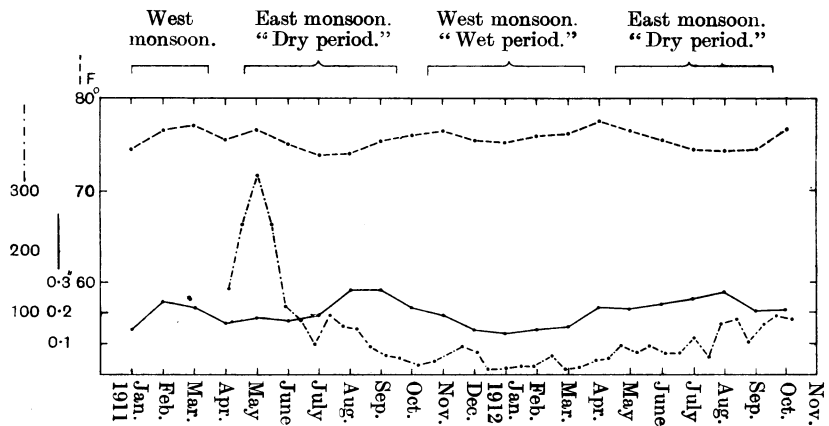


Chart XV. Java: Melang Department. First two years of plague, 1911 and 1912.

----- Temperature.
 ——— Saturation deficiency.
 - · - · - Plague deaths.

little variation in the temperature and saturation deficiency throughout the year—the temperature keeping within the limits 74–77.5° F. and the saturation deficiency within the limits .13–.27 of an inch. The climate is not at any time unfavourable to the spread of plague, and it is not surprising to find that there is no marked epidemic season and that plague occurs with apparent indifference at all times of the year. The sudden rise and fall of the disease after its introduction cannot be explained on the grounds of adverse conditions of temperature or saturation deficiency and may be due to some hitherto unrecognised cause. Plague continued in epidemic form in the Melang Department

throughout the year 1913 (see Chart XVI), the number of cases increasing from the month of August onwards.

The climate of Passuruan is said to resemble that of Surabaya and Maduin (Java). It will be observed by a reference to the chart (see Chart XVII) that, on the whole, it is somewhat drier and hotter than Melang and that towards the end of the dry season the mean temperature exceeds 80° F. with a saturation deficiency of .35 of an inch,

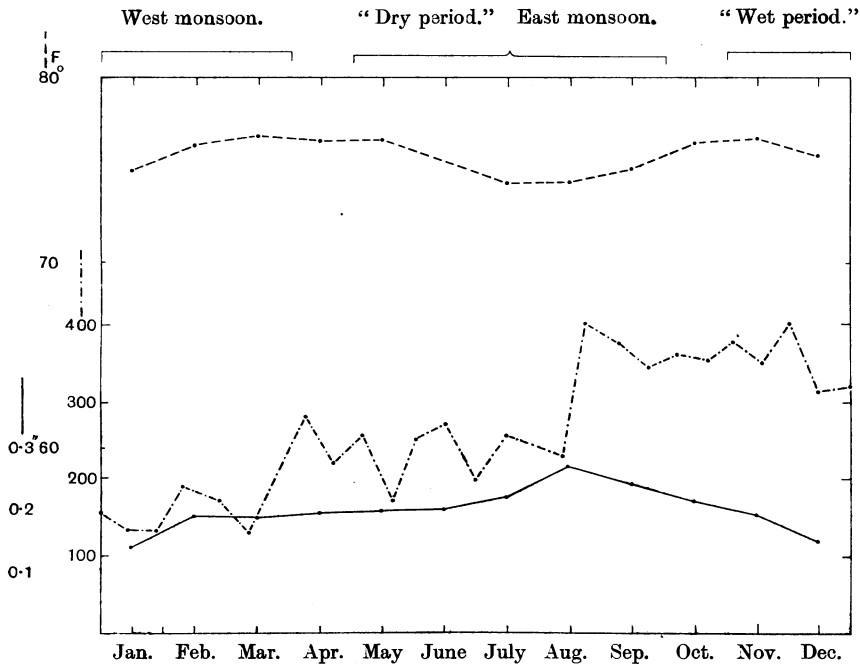


Chart XVI. Java: Melang Department. The plague epidemic of 1913.

- Temperature. (Average of 1911 and 1912.)
- Saturation deficiency. (Average of 1911 and 1912.)
- · - · - Plague deaths.

climatic conditions unfavourable for plague in India. A small number of plague cases occur at these places throughout the year and there does not appear to be any obvious epidemic season.

The climate of Mauritius is similar to that of Java except that the temperature range is considerably greater, approaching 80° F. in the months of December and January (see Chart XVIII) and falling below 70° F. during the months June, July and August. The saturation

896 *Influence of Saturation Deficiency and Temperature*

deficiency is confined between the limits .13 and .27 of an inch. The chart shows the course of the first epidemic, plague being introduced into Mauritius from Madagascar in December 1898. The data given in the chart are abstracted from particulars given in the Report by the Acting Director of the Medical and Health Department of Mauritius (7). The disease did not get much of a foothold in the island during the warm weather, though, as we know from experience elsewhere, the climatic conditions were at no time unfavourable to the spread of plague. With the setting in of the cooler weather in June a rapid increase in the

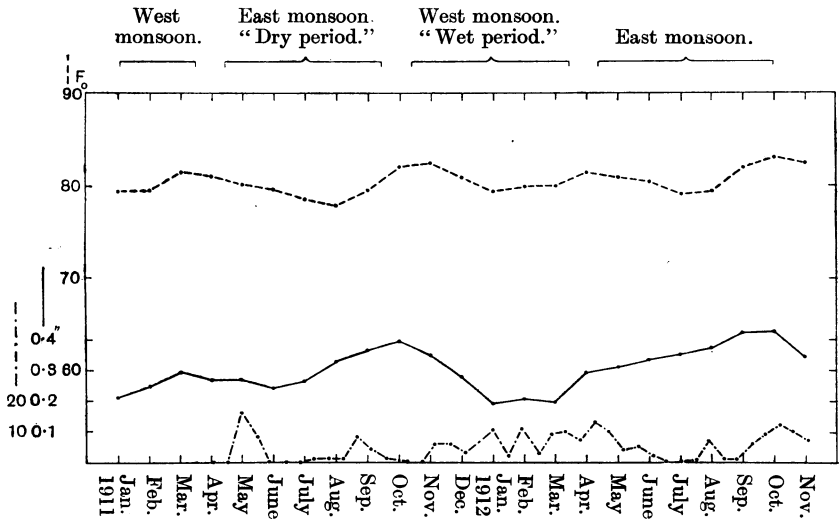


Chart XVII. Java: Surabaya and Maduin

- Temperature.
- Saturation deficiency.
- Plague deaths.

number of cases took place and the epidemic in the Port-of-entry, Port Louis, where the disease was first introduced, reached its height in August–September 1899.

From Port Louis other parts of the island in turn became infected, and subsidiary epidemics took place, which ran their own course, uninfluenced apparently by climatic conditions. The little epidemic at Pamplousses, for example, reached its height in October and the outbreak at Plaines Wilhems was still increasing at the end of the year. These circumstances suggest that in places where the combined

effects of temperature and saturation deficiency are at no time unfavourable to the occurrence and spread of plague, other factors come into play in determining the local epidemic.

It would thus appear that while the combined effects of temperature and saturation deficiency have in the majority of cases an influence on the incidence and course of plague epidemics, yet, under certain conditions, such epidemics come to an end at a time when the climatic conditions are presumably favourable for a continuance of the disease.

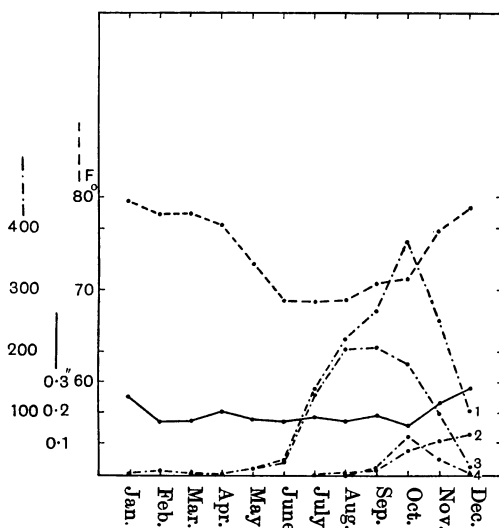


Chart XVIII. Mauritius. The first epidemic, 1899.

- Temperature.
- Saturation deficiency.
- Plague cases. 1, Whole Island; 2, Plaines Wilhems; 3, Port Louis; 4, Pamplemousses.

In these cases other factors must come into play, and attention is directed to the work of the Commission in connection with the seasonal breeding of rats, the decrease in the numbers of rats during epidemic periods and the accompanying increase in the proportion of immune to susceptible rats. The adverse influence of high temperature and saturation deficiency may be explained by their effect on the duration of life of the rat flea, *Xenopsylla cheopis*, when separated from its host.

When the mean temperature rises above 80° F. and when such rise is accompanied by an increase of the saturation deficiency to above

898 *Influence of Saturation Deficiency and Temperature*

·30 of an inch, plague cannot maintain itself in epidemic form, though a high temperature *per se* may not bring about the termination of a plague epidemic. Many examples can be adduced of plague epidemics coming to an end when the temperature remains well below 80° F. and in such cases the determining factor appears to be the rising of the saturation deficiency to over ·30 of an inch.

Plague epidemics do not, as a rule, arise when the mean temperature is above 80° F. for the reason that at such temperatures it is quite exceptional to find a sufficiently low saturation deficiency. When, however, a high temperature occurs with a low saturation deficiency, plague epidemics do arise and maintain themselves. In Rangoon, where the temperature, although above 80° F. for over nine months in every year, is associated with an exceptionally low saturation deficiency, plague occurs at all seasons of the year. The autumnal recrudescences of plague in Bombay are found associated with a mean temperature of over 80° F. but with a low saturation deficiency of less than ·20 of an inch.

Generally speaking, it may be said that there is a critical saturation deficiency for each range of temperature. At 80° F. this critical saturation deficiency appears to be of the order of ·30 of an inch. At lower ranges of temperature a higher degree of deficiency is needed to suppress the epidemic, while at higher temperatures a somewhat lower deficiency will suffice.

Summary.

1. Plague does not maintain itself in epidemic form when the temperature rises above 80° F. accompanied by a saturation deficiency of over ·30 of an inch.
2. Plague epidemics are rapidly brought to an end in the presence of a high saturation deficiency even when the mean temperature throughout and after the termination of the epidemic has been considerably below 80° F.
3. Plague epidemics may commence and increase in intensity when the mean temperature is well above 80° F., provided that the saturation deficiency is below ·30 of an inch.
4. In some districts in India and in certain tropical islands (*e.g.* Java, Mauritius) where the climatic conditions are at all times of the year favourable to the incidence and spread of plague, the disease may occur indifferently at all seasons.

I desire here to express my thanks to Dr C. J. Martin, Director of the Lister Institute, at whose suggestion the above investigation was undertaken, for his kindly help and criticism during the progress of the work in question.

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