THE PROBLEM OF THE SEASONAL PREVALENCE OF PLAGUE.

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(With 3 Charts.)

The British Indian Plague Commission has demonstrated irrefutably, both under experimental and natural conditions, that the rat flea is the link between plague in rats and men; also that increase and decrease of the flea index under the influence of climatic factors are reflected in the course of the epidemic and in the periodical occurrence of the disease.

In the same degree as temperatures between 70 and 80° F. (21–26·5° C.) prove to be favourable to the life and growth of the rat flea, similarly the temperature becomes deleterious—*and this applies to the period of infectivity* of the rat flea as well—if the average surpasses this limit, especially when the mean temperature attains 85° F. (29·5° C.) or more. This explains how in many districts, where pronounced seasonal changes with great variation in temperature exist, plague grows to epidemic proportions in the months of the year favourable to the development of the rat flea, and declines to sporadic cases or completely disappears in the unfavourable months.

Besides a high temperature, a low relative humidity is deleterious to the rat flea. This makes it comprehensible why a seasonable prevalence, independent of the temperature, is also observed in districts where the mean daily temperature never reaches 85° F., but where the relative humidity decreases to 50 per cent. or less.

Next to the influence of climatic conditions on the rat flea, other factors which may influence the course of plague have been discussed. Amongst others there is the possibility of seasonal variation in the density of the rat population, caused by the existence of a definite breeding season of the house rat. Breeding may occur throughout the year. Although the curve of pregnancy presents fluctuations, these are not large enough for pronounced differences to be expected in the density of the rat population. Naturally the number of rats decreases considerably in the course of the epizootic, whereas the proportion of immune to susceptible rats increases, and therefore undoubtedly the cooperation of these factors will influence the termination of the epizootic and also the epidemic. But all epizootics are essentially characterised by these factors, independent of locality and season. Therefore they can explain the intermittent character of an epidemic, but not its regular appearance at the same time of the year, *i.e.* its typical periodical course.

Other possibilities, such as variations in the virulence of the plague bacillus and seasonal alterations in the life habits of the rat population, may be eliminated upon closer inquiry. Therefore the seasonal prevalence of plague is carried back almost exclusively to atmospheric conditions, with their unmistakable influences on the flea in all stages of its life history. Although this may render the fact acceptable that different districts with extremely diverging climatic conditions each show their own seasonal prevalence and their own off-season, the influence of temperature and humidity on the course of the epidemic is far from clear in all instances.

Therefore Brooks[1] tried to obtain more precise information than could be afforded by the relative humidity figures. He believed that he had acquired this through the figures of the saturation deficiency. This indicates the absolute difference between the actual tension of aqueous vapour in the atmosphere and the tension of aqueous vapour that would be present in a saturated atmosphere of the same temperature. This yields more accurate information as to the drying capacity of the air at the temperature under consideration. According to Brooks, a temperature of 80° F. (26·5° C.) or over should always be combined with a saturation deficiency of at least 0·30 in. (7·62 mm.). Thus the supposition is obvious, that the prompt decline of the epidemic is caused by the combination of both factors. At a low temperature, however, a much higher saturation deficiency is required before the same condition is attained. With the aid of charts of different localities, Brooks thought he had demonstrated that in almost all districts in India, at every range of temperature, a critical saturation deficiency occurs, at which the epidemic declines. In a single district only, the combination of both factors remains favourable during the whole year. Therefore, here, the decline must be ascribed to other causes.

Examination of Brooks' charts certainly shows that the periodical course of plague is in better agreement with the saturation deficiency than with the relative humidity. Nevertheless, much remains obscure: often the increase of the epidemic commences at a moment when both temperature and saturation deficiency are still high, or the epidemic declines before both factors have passed the deleterious limit. This is especially evident when it is kept in mind that temperature and humidity only indirectly influence the epidemic through alterations in the flea index, resulting in alterations in the extent of the epizootic. Fluctuations of these factors cannot reflect in the course of the epidemic until at least several months later. Thus, upon closer analysis of the curves, in many places discrepancies in the incidence of the epidemic can be pointed out, which cannot be explained satisfactorily by means of the saturation deficiency.

As regards conditions in Java, it must be mentioned that, although this island has a pronounced change of monsoons, due to its equatorial sea climate, the temperature remains practically uniform. During the North-West monsoon, from November till the end of April, during which the heaviest rainfall

[1] *Plague Supplement* (1917), **5**, 881.

takes place, the temperature is slightly lower and the relative humidity slightly higher than during the dry South-East monsoon from May till the end of October. But even in the hottest months (October, November) the mean daily temperature remains far under 85° F. (29·5° C.), whereas the relative humidity never reaches 60 per cent., not even in the driest months (August, September).

Thus, in Java a less pronounced periodical incidence of the epidemic may be expected *a priori*, especially in mountainous regions where temperature and humidity continually offer optimal life conditions to the flea. After its initial occurrence in the Malang Department, where it first assumed an epidemic character and raged in 1911–15, plague showed indeed an irregular course with many remissions and without a trace of an off-season. From the data compiled by van Loghem and Swellengrebel[1], Brooks also plotted a saturation deficiency curve for Malang. From the fact that the deficiency varies within the limits of 0·13 and 0·27 of an inch (3·3 and 6·8 mm.) and the temperature fluctuates between 74° and 77·5° F. (23° and 25° C.), Brooks concludes that it is not surprising to find there is no marked epidemic season and that plague occurs with apparent indifference at all times of the year.

This may be true for the Malang Department, but in several other districts a definite periodicity is undeniable. In the Department of Kediri, where the disease raged epidemically in 1912–16, the height of the epidemic was always reached in the fourth quarter. In the town of Soerabaja the apex of the epidemic (of extremely benign character) is always reached round about the end of the year. In the town of Soerakarta, probably infected from east Java in 1915, plague occurred sporadically for months; in September it rapidly increased and reached its apex in December of the same year. Six years later it was infected for the second time, now from the north-west, and the epidemic attained its maximum in January 1922, one month later.

Also during the severe epidemics, which raged in the years 1918–23 in the mountainous region of mid Java, especially in the Residency of Kedoe, the apex was always reached about the end of the year, either slightly after (Department of Temanggoeng, January–February 1920), slightly before (Department of Wonosobo, October 1920), or precisely at the end (Department of Magelang, December 1921). The same incidence was observed in west Java, where the disease has assumed epidemic proportions since 1924 in the hinterland of Cheribon: an increase in the third quarter, which reaches its apex in the fourth quarter or later; then the epidemic declines and reaches its lowest point in the second quarter, especially in May and June.

Thus, undoubtedly, a periodic fluctuation exists, which may not be considered as a seasonal prevalence in its usual meaning, however, because both the periods of increase and of decline, remarkably, do not correspond with the months, which apparently offer the most favourable climatic conditions. The increase starts in the period of greatest heat and dryness: the saturation deficiency usually reaches its highest point in September, the temperature in

[1] *Zeitschr. f. Hyg. u. Infektionskr.* (1914), **78**, 141.

October, at least in mountainous regions. The decline of the epidemic occurs in the middle of the wet monsoon, when both saturation deficiency and temperature show a low monthly average.

In approaching this problem, a close knowledge of the fluctuations of the normal flea index and its possible variations under the influence of the epizootic is a first requirement. In a plague-free district in the Malang Department, van Loghem and Swellengrebel found a very low flea index with insignificant

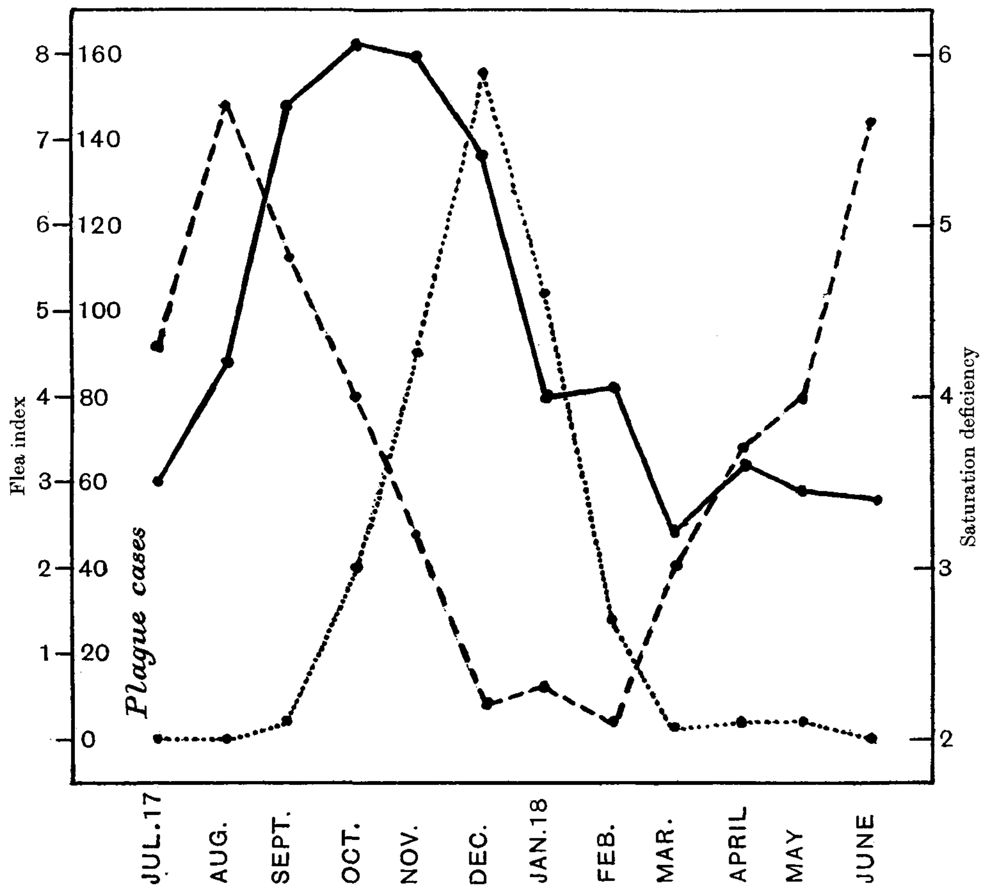

Chart 1. Temanggoeng (mid Java), 1917–18.

- - - - - sat. deficiency ——— flea index .... plague (1919–20)

fluctuations. These results, however, were obtained with rats which had been transported a long distance without adequate precautions against flea loss; this made new investigations desirable, and I attacked the problem afresh as follows:

My observations were conducted in 1917–18 in the mountain town of Temanggoeng (580 m. alt.) in the Residency of Kedoe, at the time completely free from plague[1]. At least 200 rats were captured monthly and they were

[1] *Reports of the Netherlands Indian Civil Medical Service* (1924), p. 164.

always examined on the spot. The results are recorded in Chart 1, which only shows the *X. cheopis* index of the common house rat, *R. r. diardi* jentink.

Chart 1 not only proves that the normal flea index shows a very marked fluctuation (from 3·0 to 8·1, subsequently decreasing to 3·0 and less), but also that the course of these fluctuations presents the same picture as has been described above: start of the increase during the driest months (August, September), apex in October–November; start of the decrease in December, right in the middle of the wet monsoon. Two years later, in this little town, there occurred a serious epidemic which coincided with the curve of the flea index 1917–18, but 2 months later. This supported the view that also in 1919–20 the same fluctuation of the flea index had occurred.

These investigations were continued in subsequent years in the town of Bandoeng in west Java (710 m. alt.), the capital of the mid-Priangan Residency, partly before the first cases of plague occurred (1924–6), partly afterwards (from mid 1929 to mid 1931). The investigations during 1924–6 included 5193 rats, captured in all the eight sections into which the town was divided. Every

Table I. *Flea index:* X. cheopis *at Bandoeng.*

	1924	1925	1926	1929	1930	1931
January	—	4·76	8·38	—	7·10	5·11
February	—	5·08	**9·36**	—	5·67	4·92
March	5·83	4·09	—	—	5·27	3·77
April	4·06	4·02	—	—	4·52	4·63
May	3·71	**3·57**	—	—	3·66	**3·12**
June	**2·95**	**3·79**	—	—	**3·14**	4·06
July	3·48	4·44	—	3·98	3·28	—
August	4·65	5·26	—	6·88	5·20	—
September	6·28	4·84	—	6·25	4·56	—
October	6·31	6·12	—	7·06	6·94	—
November	**11·05**	5·60	—	**8·97**	6·70	—
December	7·34	7·22	—	7·76	**7·40**	—

month at least a hundred rats were captured in two sections. This was repeated every four months in the same sections. During the years 1929–31, 8118 rats were captured. Now the town was divided into six sections and every other month the same three sections were investigated. In every section at least a hundred rats were captured.

The above-mentioned number of 13,311 rats consists of common house rats, *Rattus rattus diardi* exclusively. The extremely rarely captured specimens of *R. r. brevicaudatus* and of *R. r. roquei* are not included.

The fleas comprise *Xenopsylla cheopis*; a few specimens of *Stivalius cognatus* (obs. *Pygiopsylla ahalae*) have been discarded. *X. astia* does not occur in Bandoeng, nor in other mountainous districts of Java and cannot therefore obscure the problem.

The data obtained are recorded in Table I and Charts 2 and 3. As pregnancy in house rats in Bandoeng shows irregular fluctuations, figures relating thereto are not charted.

In Charts 2 and 3 the flea index also shows a very marked fluctuation, which, in the years 1924–5, runs practically parallel with the Temanggoeng curve seven years before (1917–18): beginning of increase in August, apex in November, decrease in December and lowest point in May–June. The 1925–6 curve shows the same beginning of the increase, a very slow rise, however, and

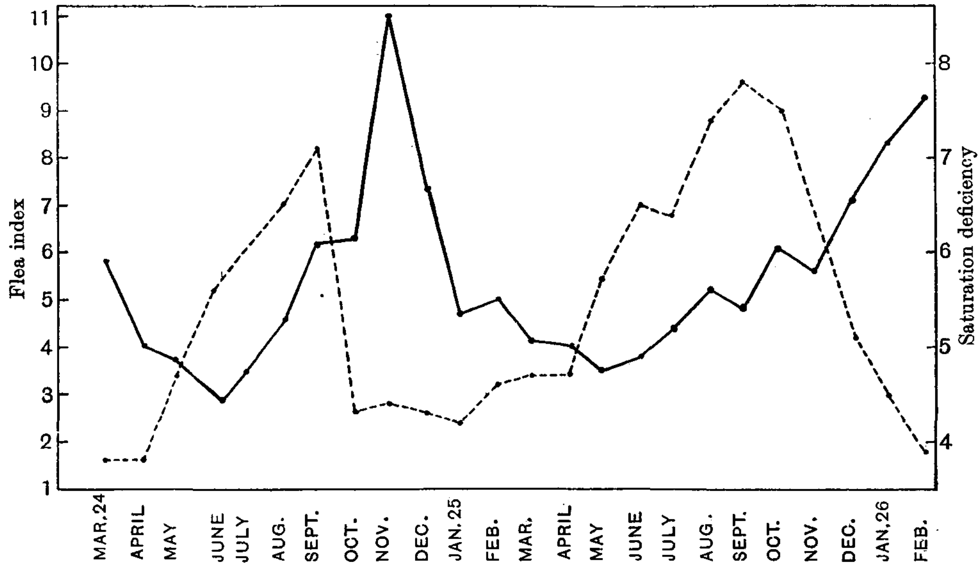

Chart 2. Bandoeng (west Java), 1924–6.

——— flea index - - - - - - sat. deficiency

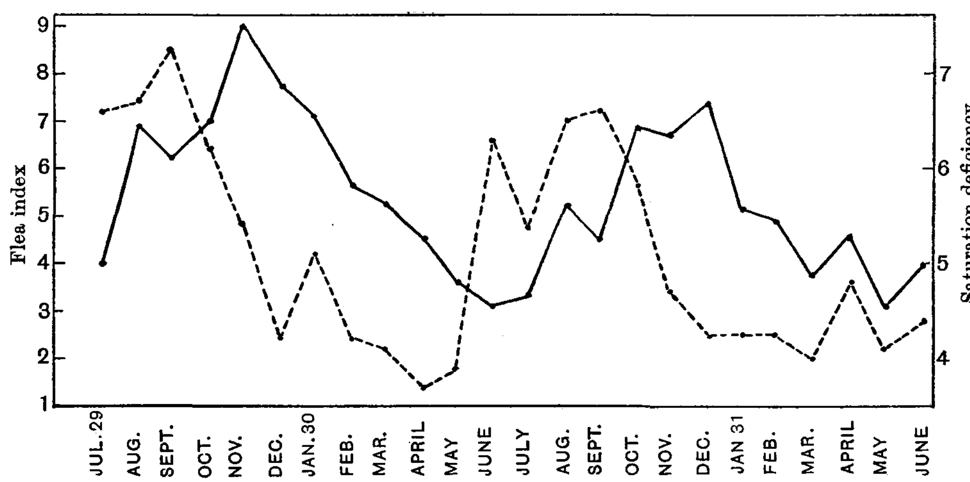

Chart 3. Bandoeng (west Java), 1929–31.

——— flea index - - - - - - sat. deficiency

finally reaches its apex in February, thus corresponding more with the course of the epidemics, which reach their height in the first quarter.

The flea index of 1929–30 presents practically the same picture as that of

1924–5: the increase commences in August, reaches its apex in November and decreases in December till it reaches its lowest point in June.

Neither does the 1930–1 curve differ, although the flea index fails to reach the same height: start of the increase in August, apex in December, prompt decline in January. The curve seems less regular, but this is due to its having been plotted from alternate captures in complexes of three sections, one of which constantly yielded a higher flea index than the other. Thus, comparison of the flea figures every other month shows a very regular increase and decrease: (*a*) 3·14, 5·20, 6·94, 7·40, 4·92, 4·63, 4·06; (*b*) 3·28, 4·56, 6·7, 5·11, 3·77, 3·12.

In May 1929 the first case of human plague was diagnosed in Bandoeng. Since, the disease has spread over the greater part of the town, without however attaining epidemic proportions. From mid 1929 till mid 1930, 220 cases occurred, with a maximum of 39 in January, whereas from mid 1930 till mid 1931 the number of cases was but 64. This is indeed a most peculiar course, as both from climatic and dwelling conditions a rapid development of a severe

Table II.

	Free from plague		Plague	
Flea figures	1924–5	1925–6	1929–30	1930–1
Flea index:				
Average	4·64	5·56	5·86	4·95
Highest monthly average	11·05	9·36	8·97	7·40
Lowest ,, ,, ...	2·95	3·79	3·14	3·12
Flea carriers:				
Average percentage	90·0 %	92·3 %	92·3 %	91·1 %
Highest monthly average percentage	99·0 %	100·0 %	97·1 %	99·3 %
Lowest ,, ,, ,,	80·7 %	83·7 %	84·4 %	81·9 %
Carriers of 10 or more fleas:				
Average percentage	17·2 %	16·9 %	19·9 %	15·3 %
Highest monthly average percentage	48·0 %	34·3 %	37·0 %	26·6 %
Lowest ,, ,, ,,	4·6 %	6·3 %	5·7 %	3·5 %
Largest number of fleas per rat ...	66	52	69	46

epidemic might rather be expected. Thus, as is shown in Table II, no influence whatever of the epizootic on the flea index has so far been discovered.

The yearly average fluctuates between 4·64 and 5·86, the highest monthly average is even higher during the years 1924–6 than during the years 1929–31. Both the average percentage of flea carriers and the fluctuation of the monthly percentages show exactly the same picture during all four years. This also holds as regards the percentages of the flea carriers with ten or more fleas (deduced from the total number of flea carriers). Finally, the largest number of fleas, collected from one rat, is not lower during the period free from plague than during the succeeding plague period.

As regards the influence of the saturation deficiency on the fluctuations of the number of fleas per rat, it shows that both curves do not intersect but rather run parallel. The flea index does indeed reach its apex at the moment that the saturation deficiency has already decreased considerably, but this decrease takes place so rapidly that its favourable influence on the flea cannot yet be perceptible at that moment. Thus the increase of the flea index begins during the months of the highest saturation deficiency, whereas its decrease is maintained during the wet monsoon with the lowest saturation deficiency. Especially the years 1929–31 show that the flea curve almost completely follows the saturation deficiency curve about two months later. This therefore points to an opposite influence and justifies the supposition that within certain limits of temperature and relative humidity an increasing and high saturation deficiency stimulates the life and development of the flea, whereas a decreasing and low saturation deficiency is deleterious.

In this connection the experimental investigations of the British Indian Commission on the reproduction and viability of *X. cheopis* in Poona during the years 1909–12 may be called to mind[1]. They established the fact that a low relative humidity (high saturation deficiency), under the existing conditions of temperature, interfered with the development of the rat flea in all its stages. A high relative humidity (low sat. def.) on the other hand had a favourable influence, which could be enhanced considerably through artificial increase of the humidity. This proved valid during the months of excessive dryness

Table III.

	Average		% of larvae and imagines hatched out at			
			Normal humidity		Artificially increased humidity	
1911	Temp. ° F.	Relative humidity %	Larva	Flea	Larva	Flea
February	71·1	47·7	26·3	0	**41·4**	**11·8**
March	76·8	52·5	23·3	0	**39·0**	**14·3**
April	83·9	43·7	8·3	0	**42·9**	0
May	87·3	52·0	3·7	0	2·0	0
June	79·9	77·2	**44·2**	22·5	17·9	**31·6**
July	78·4	75·6	**38·1**	**20·2**	35·8	13·2
August	74·9	85·5	**28·6**	**12·5**	20·0	**1·8**
September	76·4	79·9	30·0	**5·7**	**34·4**	1·9

especially; during the months of higher humidity this difference was not so pronounced, whereas during the wet months with highest relative humidity the opposite was even observed. For, both the development of the egg into the larva and of the latter into the imago was more or less hindered during these months, when the humidity was artificially increased. Moreover, in the months of the highest relative humidity, also under normal conditions, the number of larvae hatched out and of imagines developing from the larvae was smaller than in the previous months of lower relative humidity and higher temperature. This is all clearly shown in Table III.

Regarding these results, the Commission remarks that at the existing temperature (74·9° F. in August) a relative humidity higher than 85 per cent. is evidently already harmful to the hatching of the larvae and an artificially increased humidity also has a deleterious influence on the further development into the imago. As, however, these data were partly based on extremely small numbers and in the wettest months growth of moulds was noticed in the

[1] *Plague Supplement* (1912), **3**, 300.

breeding cages, the Commission regards this information with some reserve. In the summary, the Commission leaves these data out of consideration by deciding that the development of the rat flea in all its stages is greatest in damp weather and at a moderate temperature, and that it is furthered by artificially increased humidity.

The flea curves of Temanggoeng and Bandoeng, however, the periodicity of which is unmistakable, show unquestionably that what is very rarely observed in Poona is the usual course in the mountainous parts of Java. In equable climates, such as Bandoeng, where the mean monthly temperature fluctuates between 21·6° and 23·4° C. = 70·9 and 74·1° F. (*i.e.* a difference of hardly 3° F., whereas in Poona it is over 20° F., viz. 66·8–87·3°) and where the relative humidity fluctuates between 83 and 68 per cent. (*i.e.* a difference of but 15 per cent., whereas in Poona it is more than 50 per cent., viz. 88–37 per cent.), it shows that a slight decrease in the relative humidity to ± 70 per cent., which however implies a distinct increase in the saturation deficiency, favours the number of fleas, whereas an increase to 80 per cent. and more (through which the saturation deficiency rapidly falls) acts deleteriously.

That, however, the favourable influence of a low relative humidity is confined to narrow limits is clearly shown by the divergent course of the flea index during 1925 with its extremely hot and dry east monsoon. The mean relative humidity in 1925 not only dropped to its minimum of 68 per cent., but remained at this level in August–October, whereas the average temperature during September–November stayed at its maximum of 23·3–23·4° C. (*i.e.* ± 74° F.) with a top day temperature of nearly 85° F. These abnormally hot and dry months, during which the saturation deficiency reached the extreme limit of 7·62 mm. (0·3 in.), markedly affected the flea index, which showed a very slow increase and only reached its apex in February 1926, *i.e.* five months delayed with regard to the highest saturation deficiency. After running parallel initially, both curves finally cross.

I cannot as yet explain how the relative humidity in the mountainous parts of Java influences the development and viability of the flea. In Temanggoeng, during seven months (August 1917–February 1918), I checked the number of ova per flea and the production of larvae. The first varied between 2·8 and 3·1, the latter between 50 per cent. and 58 per cent.: thus there were practically no fluctuations. Similar investigations are still required for Bandoeng on all periods of development of the flea, both on the period of generation and viability.

Summary.

1. The epidemic spread of plague in Java usually shows periodicity in that the increase commences in the third quarter, the driest period of the year, the apex being reached in the last months of the year. Afterwards, still in the middle of the wet monsoon, the decrease commences and reaches its lowest point in the second quarter.

2. This seasonal course of plague—in the mountainous parts of Java at least—corresponds with a distinct fluctuation in the flea index during the same period.

3. Whereas under the climatic conditions of the mountainous regions of Java the flea index usually follows the rise and fall of the saturation deficiency, it has been shown that in British India the influence of the saturation deficiency is in an exactly opposite direction.

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