(NEW SERIES.) No. 46.

SCIENTIFIC MEMOIRS

BY

OFFICERS OF THE MEDICAL AND SANITARY DEPARTMENTS

OF THE

GOVERNMENT OF INDIA

MALARIA IN THE PUNJAB

BY

MAJOR S. R. CHRISTOPHERS, M.B., I.M.S.,
Assistant to the Director, Central Research Institute, Kasauli

---

ISSUED UNDER THE AUTHORITY OF THE GOVERNMENT OF INDIA BY THE SANITARY COMMISSIONER WITH THE GOVERNMENT OF INDIA, SIMLA

CALCUTTA
SUPERINTENDENT GOVERNMENT PRINTING, INDIA
1911

Price Rs. 2 or 3s.

(NEW SERIES.) No. 46.

SCIENTIFIC MEMOIRS

BY

OFFICERS OF THE MEDICAL AND SANITARY DEPARTMENTS

OF THE

GOVERNMENT OF INDIA

MALARIA IN THE PUNJAB

BY

MAJOR S. R. CHRISTOPHERS, M.B., I.M.S.,
Assistant to the Director, Central Research Institute, Kasauli

ISSUED UNDER THE AUTHORITY OF THE GOVERNMENT OF INDIA BY THE SANITARY COMMISSIONER WITH THE GOVERNMENT OF INDIA, SIMLA

CALCUTTA
SUPERINTENDENT GOVERNMENT PRINTING, INDIA
1911

Agents for the Sale of Books published by the Superintendent of Government Printing, India, Calcutta.

IN ENGLAND.

Mr. E. A. ARNOLD, 41 and 43, Maddox Street, Bond Street, London, W.

Messrs. CONSTABLE & Co., 10, Orange Street, Leicester Square, W.C.

Messrs. KEGAN PAUL, TRENCH, TRÜBNER & Co., 43, Gerrard Street, Soho, London, W.

Mr. BERNARD QUARITCH, 11, Grafton Street, New Bond Street, W.

Messrs. P. S. KING & SON, 2 and 4, Great Smith Street, Westminster.

Messrs. H. S. KING & Co., 65, Cornhill, and 9, Pall Mall, London.

Messrs. GRINDLAY & Co., 54, Parliament Street, London, S.W.

Mr. T. FISHER UNWIN, 1, Adelphi Terrace, London, W.C.

Messrs. W. THACKER & Co., 2, Creed Lane, London, E.C.

Mr. B. H. BLACKWELL, 50 and 51, Broad Street, Oxford.

Messrs. DEIGHTON BELL & Co., Cambridge.

Messrs. LUZAC & Co., 46, Great Russell Street, London, W.C.

ON THE CONTINENT.

Mr. OTTO HARRASSOWITZ, Mr. KARL HIERSEMANN, } Leipzig.

Messrs. R. FRIEDLÄNDER & SOHN, Berlin, W.N., Carlstrasse, 11.

Mr. ERNEST LEROUX, 28, Rue Bonaparte, Paris.

Mr. MARTINUS NIJHOFF, The Hague, Holland.

IN INDIA.

Messrs. THACKER, SPINK & Co., Calcutta and Simla.

Messrs. NEWMAN & Co., Calcutta.

Messrs. R. CAMBRAY & Co., Calcutta.

Messrs. S. K. LAHIRI & Co., Calcutta.

Messrs. B. BANERJEE & Co., Calcutta.

The Calcutta School Book and Useful Literature Society, 1, Wellington Square, Calcutta.

Messrs. HIGGINBOTHAM & Co., Madras.

Messrs. V. KALYANARAMA IYER & Co., Madras.

Messrs. G. A. NATESAN & Co., Madras.

Messrs. S. MURTHY & Co., Madras.

Messrs. THOMPSON & Co., Madras.

Messrs. TEMPLE & Co., Madras.

Messrs. COMBRIDGE & Co., Madras.

Messrs. P. R. RAMA IYER & Co., Madras.

Messrs. THACKER & Co., LD., Bombay.

Messrs. A. J. COMBRIDGE & Co., Bombay.

Messrs. D. B. TARAPOREVALA, SONS & Co., Bombay.

Mrs. RADHABAI ATMARAM SAGOON, Bombay.

Mr. SUNDER PANDURANG, Bombay.

Messrs. GOPAL NARAYAN & Co., Bombay.

Superintendent, American Baptist Mission Press, Rangoon.

RAI SAHIB M. GULAB SINGH & SONS, Mufid-i-Am Press, Lahore and Calcutta.

Mr. N. B. MATHUR, Superintendent, Nazair Kanun Hind Press, Allahabad.

Messrs. A. CHAND & Co., Punjab.

Messrs. A. M. & J. FERGUSON, Ceylon.

Babu S. C. TALUKDAR, Proprietor, Students and Company, Cooch Behar.

List of numbers of Scientific Memoirs by Officers of the Medical and Sanitary Departments of the Government of India (New Series) published previous to the present issue.

No. 1. Standardisation of Calmette's Anti-Venomous Serum with Pure Cobra Venom: the Deterioration of this Serum through keeping in India, by *Captain G. Lamb, I.M.S., and Wm. Hanna, Esq., M.B.* Price As. 3 or 4*d.*

No. 2. Malaria in India, by *Captain S. P. James, I.M.S.* Price Re. 1-8 or 2*s.* 3*d.*

No. 3. Some Observations on the Poison of Russell's Viper (Daboia Russellii), by *Captain G. Lamb, I.M.S., and Wm. Hanna, Esq., M.B.* Price As. 5 or 6*d.*

No. 4. On the Action of the Venoms of the Cobra and of the Daboia on the Red Blood corpuscles and on the blood plasma, by *Captain G. Lamb, I.M.S.* Price As. 8 or 9*d.*

No. 5. Specificity of Anti-Venomous Sera, by *Captain G. Lamb, I.M.S.* Price As. 3 or 4*d.*

No. 6. First Report on the Anti-Malarial Operations in Mian Mir, 1901–03, by *Captain S. P. James, I.M.S.* Price As. 12 or 1*s.* 2*d.*

No. 7. Some Observations on the Poison of the Banded Krait (Bungarus Fasciatus), by *Captain G. Lamb, I.M.S.* Price As. 8 or 9*d.*

No. 8. A Preliminary Report on a Parasite found in Patients suffering from Enlargement of the Spleen in India, by *Lieutenant S. R. Christophers, I.M.S.* Price Re. 1-8 or 2*s.* 3*d.*

No. 9. Second Report of the Anti-Malarial Operations at Mian Mir, 1901–03, by *Lieutenant S. R. Christophers, I.M.S.* Price As. 10 or 1*s.*

No. 10. Specificity of Anti-Venomous Sera (Second Communication), by *Captain G. Lamb, I.M.S.* Price As. 8 or 9*d.*

No. 11. On a Parasite found in persons suffering from Enlargement of the Spleen in India—Second Report, by *Lieutenant S. R. Christophers, I.M.S.* Price Rs. 2 or 3*s.*

No. 12. On the Morphology, Teratology, and Diclinism of the Flowers of Cannabis, by *Major D. Prain, I.M.S.* Price As. 14 or 1*s.* 4*d.*

No. 13. Oriental or Delhi Sore, by *Captain S. P. James, I.M.S.* Price As. 10 or 1*s.*

No. 14. On a Parasite found in the White Corpuscles of the Blood of Dogs, by *Captain S. P. James, I.M.S.* Price As. 10 or 1*s.*

No. 15. On a Parasite found in persons suffering from Enlargement of the Spleen in India—Third Report, by *Lieutenant S. R. Christophers, I.M.S.* Price As. 10 or 1*s.*

No. 16. The Specificity of Anti-Venomous Sera with special reference to a Serum prepared with the Venom of the Daboia Russellii, by *Captain G. Lamb, I.M.S.* Price As. 6 or 7*d.*

No. 17. Snake-Venoms in relation to Hæmolysis, by *Captain G. Lamb, I.M.S.* Price As. 6 or 7*d.*

No. 18. Hæmogregarina Gerbilli, by *Lieutenant S. R. Christophers, M.B., I.M.S.* Price As. 10 or 1*s.*

No. 19. On Kala Azar, Malaria and Malarial Cachexia, by *Captain S. P. James, M.B., I.M.S.* Price Re. 1-4 or 1*s.* 11*d.*

No. 20. Serum-Therapy of Plague in India; Reports by Mr. W. M. Haffkine, C.I.E., and various officers of the Plague Research Laboratory, Bombay, by *Lieutenant-Colonel W. B. Bannerman, M.D., B.Sc., F.R.C.S., I.M.S.* Price As. 14 or 1*s.* 4*d.*

No. 21. On the Standardisation of Anti-Typhoid Vaccine, by *Captain George Lamb, M.D., I.M.S.* (*Director, Pasteur Institute of India*), and *Captain W. B. C. Forster, M.B., D.P.H., I.M.S.* Price As. 6 or 7*d.*

No. 22. Mediterranean Fever in India: Isolation of the Micrococcus Melitensis, by *Captain George Lamb, M.D., I.M.S.*, and *Assistant Surgeon M. Kesava Pai, M.B., C.M.* (*Madras*). Price As. 10 or 1*s.*

No. 23. The Anatomy and Histology of Ticks, by *Captain S. R. Christophers, M.B., I.M.S.* Price Rs. 3 or 4*s.* 6*d.*

No. 24. On a Parasite found in the White Corpuscles of the blood of Palm Squirrels, by *Captain W. S. Patton, M.B., I.M.S.* Price As. 12 or 1*s.* 2*d.*

No. 25. On the importance of Larval Characters in the Classification of Mosquitoes, by *Captain S. R. Christophers, M.B., I.M.S.* Price As. 8 or 9*d.*

No. 26. Leucocytozoon Canis, by *Captain S. R. Christophers, M.B., I.M.S.* Price As. 12 or 1*s.* 2*d.*

No. 27. Preliminary Report on the Development of the Leishman-Donovan Body in the Bed Bug, by *Captain W. S. Patton, M.B., I.M.S.* Price As. 8 or 9*d.*

No. 28. The Sexual Cycle of Leucocytozoon Canis in the Tick, by *Captain S. R. Christophers, M.B.. I.M.S.* Price As. 12 or 1*s.* 2*d.*

No. 29. Piroplasma Canis and its Cycle in the Tick, by *Captain S. R. Christophers, M.B., I.M.S.* Price Rs. 2 or 3*s.*

No. 30. The Theory and Practice of Anti-Rabic Immunisation, by *Captain W. F. Harvey, M.B., I.M.S.*, and *Captain Anderson McKendrick, M.B., I.M.S.* Price As. 12 or 1*s.* 2*d.*

No. 31. The Development of the Leishman-Donovan Parasite in Cimex Rotundatus—Second Report, by *Captain W. S. Patton, M.B., I.M.S.* Price Re. 1 or 1*s.* 6*d.*

No. 32. An Enquiry on Enteric Fever in India carried out at the Central Research Institute, Kasauli, under the direction of Lieutenant-Colonel D. Semple, M.D., and Captain E. D. W. Greig, M.D. Price Re. 1-2 or 1*s.* 9*d.*

No. 33. The Production of Alkali in Liquid Media by the Bacillus Pestis, by *Lieutenant-Colonel W. B. Bannerman, M.D., B.Sc., I.M.S.* Price As. 5 or 6*d.*

No. 34. Standards of the Constituents of the Urine and Blood and the bearing of the Metabolism of Bengalis on the Problems of Nutrition, by *Captain D. McCay, M.B., I.M.S.* Price As. 12 or 1*s.* 2*d.*

No. 35. Black-water Fever, by *Captain S. R. Christophers, M.B., I.M.S.*, and *Dr. C. A. Bentley.*

No. 36. Observations on Rabies: with special reference to an Atrophic form of the disease occurring in animals, by *Major G. Lamb, M.D., I.M.S.*, and *Captain A. G. McKendrick, M.B., I.M.S.* Price As. 8 or 9*d.*

No. 37. Investigations on Bengal Jail Dietaries: with some observations on the influence of dietary on the physical development and well-being of the people of Bengal, by *Captain D. McCay, M.B., B.Ch., B.A.O., I.M.S.* Price Rs. 2-6 or 4*s.* 3*d.*

No. 38. Preliminary Report on the killing of Rats and Rat Fleas by Hydrocyanic Acid Gas, by *Captain W. D. H. Stevenson, M.B., I.M.S.* Price As. 8 or 9*d.*

No. 39. The Applicability to Medico-Legal Practice in India of the Biochemical Tests for the Origin of Blood-Stains, by *Lieutenant-Colonel W. D. Sutherland, M.B., I.M.S.* Price As. 8 or 9*d.*

No. 40. The Destruction of Fleas by Exposure to the Sun, by *Captain J. Cunningham, M.D., I.M.S.* Price As. 8 or 9*d.*

No. 41. Quinine and its Salts, their Solubility and Absorbability, by *Captain A. C. MacGilchrist, M.A., M.D., M.R.C.P., I.M.S.* Price As. 9 or 10*d.*

No. 21. On the Standardisation of Anti-Typhoid Vaccine, by *Captain George Lamb, M.D., I.M.S.* (*Director, Pasteur Institute of India*), and *Captain W. B. C. Forster, M.B., D.P.H., I.M.S.* Price As. 6 or 7*d.*

No. 22. Mediterranean Fever in India: Isolation of the Micrococcus Melitensis, by *Captain George Lamb, M.D., I.M.S.*, and *Assistant Surgeon M. Kesava Pai, M.B., C.M.* (*Madras*). Price As. 10 or 1*s.*

No. 23. The Anatomy and Histology of Ticks, by *Captain S. R. Christophers, M.B., I.M.S.* Price Rs. 3 or 4*s.* 6*d.*

No. 24. On a Parasite found in the White Corpuscles of the blood of Palm Squirrels, by *Captain W. S. Patton, M.B., I.M.S.* Price As. 12 or 1*s.* 2*d.*

No. 25. On the importance of Larval Characters in the Classification of Mosquitoes, by *Captain S. R. Christophers, M.B., I.M.S.* Price As. 8 or 9*d.*

No. 26. Leucocytozoon Canis, by *Captain S. R. Christophers, M.B., I.M.S.* Price As. 12 or 1*s.* 2*d.*

No. 27. Preliminary Report on the Development of the Leishman-Donovan Body in the Bed Bug, by *Captain W. S. Patton, M.B., I.M.S.* Price As. 8 or 9*d.*

No. 28. The Sexual Cycle of Leucocytozoon Canis in the Tick, by *Captain S. R. Christophers, M.B., I.M.S.* Price As. 12 or 1*s.* 2*d.*

No. 29. Piroplasma Canis and its Cycle in the Tick, by *Captain S. R. Christophers, M.B., I.M.S.* Price Rs. 2 or 3*s.*

No. 30. The Theory and Practice of Anti-Rabic Immunisation, by *Captain W. F. Harvey, M.B., I.M.S.*, and *Captain Anderson McKendrick, M.B., I.M.S.* Price As. 12 or 1*s.* 2*d.*

No. 31. The Development of the Leishman-Donovan Parasite in Cimex Rotundatus—Second Report, by *Captain W. S. Patton, M.B., I.M.S.* Price Re. 1 or 1*s.* 6*d.*

No. 32. An Enquiry on Enteric Fever in India carried out at the Central Research Institute, Kasauli, under the direction of Lieutenant-Colonel D. Semple, M.D., and Captain E. D. W. Greig, M.D. Price Re. 1-2 or 1*s.* 9*d.*

No. 33. The Production of Alkali in Liquid Media by the Bacillus Pestis, by *Lieutenant-Colonel W. B. Bannerman, M.D., B.Sc., I.M.S.* Price As. 5 or 6*d.*

No. 34. Standards of the Constituents of the Urine and Blood and the bearing of the Metabolism of Bengalis on the Problems of Nutrition, by *Captain D. McCay, M.B., I.M.S.* Price As. 12 or 1*s.* 2*d.*

No. 35. Black-water Fever, by *Captain S. R. Christophers, M.B., I.M.S.*, and *Dr. C. A. Bentley.*

No. 36. Observations on Rabies: with special reference to an Atrophic form of the disease occurring in animals, by *Major G. Lamb, M.D., I.M.S.*, and *Captain A. G. McKendrick, M.B., I.M.S.* Price As. 8 or 9*d.*

No. 37. Investigations on Bengal Jail Dietaries: with some observations on the influence of dietary on the physical development and well-being of the people of Bengal, by *Captain D. McCay, M.B., B.Ch., B.A.O., I.M.S.* Price Rs. 2-6 or 4*s.* 3*d.*

No. 38. Preliminary Report on the killing of Rats and Rat Fleas by Hydrocyanic Acid Gas, by *Captain W. D. H. Stevenson, M.B., I.M.S.* Price As. 8 or 9*d.*

No. 39. The Applicability to Medico-Legal Practice in India of the Biochemical Tests for the Origin of Blood-Stains, by *Lieutenant-Colonel W. D. Sutherland, M.B., I.M.S.* Price As. 8 or 9*d.*

No. 40. The Destruction of Fleas by Exposure to the Sun, by *Captain J. Cunningham, M.D., I.M.S.* Price As. 8 or 9*d.*

No. 41. Quinine and its Salts, their Solubility and Absorbability, by *Captain A. C. MacGilchrist, M.A., M.D., M.R.C.P., I.M.S.* Price As. 9 or 10*d.*

No. 42. The Cultivation of the Bacillus of Leprosy and the Treatment of cases by means of a Vaccine prepared from the Cultivations, by *Major E. R. Rost, I.M.S.* Price As. 8 or 9*d.*

No. 43. The Relation of Tetanus to the Hypodermic or Intramuscular Injection of Quinine, by *Lieutenant-Colonel Sir D. Semple,* Kt., *M.D.* Price As. 12 or 1*s.* 2*d.*

No. 44. The Preparation of a Safe and Efficient Antirabic Vaccine, by *Lieutenant-Colonel Sir D. Semple,* Kt., *M.D., D.P.H., R.A.M.C.* (Retired). Price As. 8 or 9*d.*

No. 45. Epidemic Dropsy in Calcutta, by *Major E. D. W. Greig, M.D., D.Sc., I.M.S.* Price Re. 1-1 or 2*s.*

Published by and on sale at the Office of the Superintendent of Government Printing, India, Calcutta. Copies are also available from all Agents for the sale of Government publications.

CONTENTS.

PART I.

Introduction.

PART II.

Autumnal Epidemic (Fulminant) Malaria.

PART III.

Determining causes of Fulminant Malaria.

PART IV.

Experimental work on the Mechanism of Fulminant Malaria.

PART V.

PART VI.

Large Maps.

I.—1908 Epidemic.

II.—1892 „

III.—Amritsar.

IV.—Rainfall, 1908.

V.—Rainfall, 1892.

Small Maps.

6.—Four small maps of Amritsar shewing mortality distribution.

7.—Plan of Delhi City.

8.—Amritsar and Gherinda thanas.

9.—Gujrat thana.

10.—Bhera and surrounding thanas.

11.—Epidemic frequency.

Charts.

1.—To shew autumnal epidemic rises.

2.—To shew effect of epidemic on dispensary admissions.

3.—To shew mortality curves for Amritsar, Palwal and Bhera.

4.—Age incidence of mortality during epidemic.

5.—Fever deaths for the years 1869—1908.

6.—Correlation of fever mortality with rainfall.

7.— „ fever, mortality, rainfall and prices.

8.—Shewing nature of "Spleen rate."

9.—Shewing nature of "Infection among native children."

All these maps and charts will be found in a pocket at the end of the Memoir. On the large coloured maps the three shades of red indicate in order of intensity a death rate during October of five, seven, and ten times the normal respectively; and the three shades of blue indicate in order of intensity a rainfall during June to September (inclusive) of over ten, over twenty, and over thirty inches respectively.

Malaria in the Punjab.

PART I.

INTRODUCTION.

CHAPTER I.

Physical Features, Population and Rainfall.

THE Punjab, one of the Provinces of India, along with the much smaller North-West Frontier Province, forms the extreme North-west corner of the Empire. Considerable areas within the political boundaries, such as Kangra, are entirely mountainous, but the main portion of the Punjab and the portion we are concerned with, since it is here that malaria assumes so great an importance, is the great alluvial plain, almost equalling in area Great Britain and carrying a population of 20,000,000, which stretches from the foot of the Himalayas until it terminates to the south in the desert of Rajputana.

The Province proper, excluding dependent States, consists of twenty-seven districts with an average area of from 3,000—4,000 square miles. Those districts situated to the West and those bordering upon the desert to the South receive but little rainfall and are comparatively sparsely inhabited. The greatest density of population is found in the districts lying in the submontane regions beneath the Himalayas and especially in the three contiguous districts, Sialkot, Amritsar and Jullunder, which together support a population of 3,025,324 with a density of from 544 to 641 persons to the square mile.

As is usual in India the rural population greatly exceeds the urban being in 1901, 88·44 per cent. of the total. But there are three cities, Delhi, Amritsar and Lahore, of over 100,000 inhabitants, 17 large towns of from 20,000 to 100,000 inhabitants and 151 towns with less than 20,000 inhabitants, the urban population in 1901 amounting to 2,595,372. The total number of villages in British territory in 1901 was 36,011, the greatest percentage of the rural population (52·7), living in villages of from 500—2,000 inhabitants.

For the most part conditions throughout these wide areas are very similar, villages consisting of solid mud built houses lie scattered over a plain, level as far as the eye can see. In parts the major portion of the land is cultivated ; in others

large tracts of bare soil lie untouched and liable during the rains to become sheets of standing water. In almost every case, except where land is particularly valuable or sandy, small towns and cities alike, since they are all built of mud or bricks made locally, are surrounded by excavations. Where the village or town is an ancient one the excavated material accumulates until a large mound is formed upon which the modern village or town is built. In such cases the surrounding excavations which have perhaps taken centuries to form are out of all proportion to the buildings now in existence. Some idea of the size and extent to which these excavations may reach can be gathered from the account given later of the city of Amritsar.

The soil of the Punjab is for the most part a fine silt deposited by the rivers whose action has actually formed the land. It is peculiarly impervious to water and is rendered more so by a tendency to the formation of a concretionary layer of so-called "Kunker" a few feet beneath the surface. Even where the soil is more sandy, water running over it gathers a fine mud which when deposited forms a highly impervious layer greatly hindering absorption, so that shallow pools often disappear as much by evaporation as by being absorbed into the soil.

The imperviousness of the soil added to the level character of the country results (wherever heavy rain falls) in large surface collections of water and even of floods temporarily submerging large tracts of country.

A curious physical feature characterising the Punjab and important in this connection is the comparative rarity of small streams. Between the Beas and the Ravi, a distance of about 50 miles, it is doubtful if more than one or two such minor streams are crossed, storm water finding its way along shallow depressions only apparent to the expert hydrologist or along artificially cut drains. At Palwal it is necessary to carry the drainage a distance of seven miles before it can be discharged into a nullah. At Amritsar the city drain extends to a distance of twelve miles before it meets a nullah and then discharges not into any deep channel but more or less on to the surface of the country.

Passing through the Punjab one might almost say that, with the exception of the rivers, the country as a whole is featureless. It is only by experience that one learns to realise that though apparently so flat there are, winding through the land, great riverains lying at a slightly lower level than the surrounding country. In the more recent of these riverains there still flow, winding in great curves from side to side, one or other of the rivers of the Punjab. Others are now deserted by the rivers which formed them, as in the case of an old riverain in the Montgomery District and an old bed of the Beas which runs through Kasur. Still older riverains have lost much of their distinctiveness, but remain nevertheless as depressed areas and retain the physical features which characterise these tracts.

All such riverains are peculiarly liable to flooding. This may take place either by rain water collecting and being unable to drain away sufficiently quickly or by

the overflow of the river which runs through them. Even deserted riverains are apt to be flooded by their original rivers when the waters in these reach an excessive height.

Another important feature of the riverains is the fact that the subsoil water is near the surface. This is equally the case whether the riverains be narrow or wide. In certain places the rivers have reduced very large tracts to their flood plain level, as has happened for example in the Jhelum riverain above Shahpur where a tract more than thirty miles long and on an average more than ten miles broad lies near flood level. Other examples are seen where the Sutlej near Ferozepore has formed a great loop northwards leaving a riverain behind it more than ten miles broad, and north of Lahore city where the thana of Muridke lies in a great depressed area crossed by old channels of the Ravi and other streams carrying the drainage from Sialkot.

Everywhere in such areas the level of the subsoil water is high and after heavy rain it may remain for months within three or four feet of the surface.

Between the rivers of the Punjab are strips of country known as the Doabs. On the whole the lands of the Doabs are at a comparatively high level and they are much less liable to floods than the riverains. But they are by no means entirely exempt ; for the peculiar conformation of the ground lends itself to the formation during heavy rains of extensive collections of water. The conditions as regards subsoil water in the Doabs is stated to depend a great deal upon the amount of irrigation to which they have been subjected. Throughout most of the Rachna Doab between the Ravi and the Chenab and the Zech Doab between the Chenab and the Jhelum the subsoil water is at a considerable depth (40 feet or more). These Doabs are not only subject to a small rainfall but have only comparatively recently been irrigated. Throughout the northern portions of the Bari Doab which lies between the Beas and Ravi and which has been for a long time heavily irrigated the level of the subsoil water on the contrary is high.

Over the Doabs rainfall precipitation tends to be diminished as will be seen from the rainfall maps. There is thus a cyclical tendency for a tract like the Zech Doab which we shall study in more detail later to have a small rainfall and a low subsoil water, and to be comparatively free from the liability to floods.

West of the Jhelum rainfall does not reach proportions sufficient to cause extensive flooding and such floods as occur are usually the effects of rivers overflowing their banks. But in the eastern half of the Punjab it is doubtful whether any large tract however situated can be considered free from the possibility of flooding should an unusually heavy monsoon rain happen to fall there.

The chief rain of the Punjab is that which falls during the south-west monsoon. This monsoon breaks as a rule in the Punjab about the middle of June and continues for about two months. The heaviest rain falls along the eastern

border and on the districts lying along the foot of the Himalayan Range. Passing westwards the fall becomes progressively less until the regions to the extreme west even in a year of heavy monsoon receive less than 10 inches at this time.

Other showers fall during the year but the preponderating effect of the monsoon will be evident from the fact that nearly three-quarters of the total average rainfall is that which falls during this period.

Before concluding our remarks on the physical features of the Punjab it will be necessary to refer briefly to the irrigation systems. As is well known the Punjab is the seat of enormous irrigation works which have brought thousands of square miles of land within the power of the ryot to cultivate. If one looks at a map of the Punjab prepared to show the distribution of the canal systems we shall see how extensively irrigation is carried on. But whilst enormous tracts are covered with a net-work of main canals and their distributaries there are other equally large areas devoid of any irrigation whatever beyond what is obtained from wells or other merely local arrangements.

These great blanks, as it were, in the irrigation system enable one, as we shall see later, to judge of the effects produced by irrigation upon malaria.

CHAPTER II.

Autumnal Epidemic Malaria.

The Punjab has always been looked upon as malarious and though it is so dry a tract the recorded death rate from fevers is higher than that for most parts of India.

A marked feature of Punjab malaria is its seasonal character. During the cold weather months and the very hot weather following them very little rain falls, and it is not until June when the monsoon sets in that the conditions become favourable to the breeding of anopheles.

Whether or not from this cause malaria remains in abeyance in the Punjab until the autumn when in greater or less degree it becomes prevalent.

The admissions for malaria among troops stationed in unhealthy places in the Punjab show very regularly an increase commencing in July or even June and reaching its greatest height in October or November. Investigations at Mian Mir show that this increase in admissions for malaria is associated with a greater prevalence of anopheles and a rise in the spleen rate in the native bazaars of the cantonment. With regard to the infection among troops and the prevalence of anopheles Wilson[1] has shown the same thing for Ferozepore.

As observations at Mian Mir have now extended over a number of years we are able to say in regard to this station that there occurs a regular fluctuation in the level, so to speak, of malaria as shown by the spleen rate and parasite rate.

This level is lowest during the months of June, July and rises highest in October, falling again during the winter months.

If we examine the mortality records of the Punjab we shall be struck by an almost exact repetition in most years of this curve. Especially before plague appeared and so profoundly modified the seasonal prevalence of deaths we find the number of deaths lowest in June and July, rising in September, highest in October and November and falling again through the early months of the year.

In a paper attached to this report[2] is given the result of a prelimmary study of the mortality statistics with reference to the investigation of epidemic disease. The principle made use of depends upon the fact that if for any given community the number of total weekly or monthly deaths is plotted out in the form of a curve this will maintain an approximately level line except when epidemic disease makes its effects seen in the form of an "epidemic rise." This result of epidemic disease in India is so enormous that we can study records of its effects even should our

---

1 Wilson : Notes on the fevers prevalent at Ferozepore in the Punjab.—*Jour. Royal Army Medical Corps, No. 6, June 1909.*

2 Christophers : Suggestions on the use of available statistics for studying Malaria in India.—*Paludism, No 1, July 1910.*

statistics not be absolutely accurate, the epidemic in such cases causing a mortality out of all proportion to that of non-epidemic times ; we can in fact, study a death curve with its periodical epidemic rises as dispassionately as we could the record of a seismograph or other recording instrument.

A very remarkable feature of these epidemic rises in the Punjab is the regularity with which those due to a particular disease tend to occupy a certain definite portion of the year. Another feature is that the form of the curve tends to be characteristic of particular diseases, the curve for cholera differing in character from those due to either plague or malaria.

In such a study we are not dependent on the diagnosis of the returns of deaths which obviously are open to grave fallacy, though we use these in helping us to interpret the curve.

Studying mortality curves from different areas of the Punjab in this way we shall be greatly struck by their similarity.

During March, April and May we may encounter during latter years an enormous rise, the effect of epidemic plague. In those years in which plague is not prevalent we shall find either a normal level maintained or slight rises associated with smallpox and other epidemic disease. About August there often occurs a remarkably sharp and sudden rise. A study of returns shows this to be the effect of cholera. Still later in October and November we come to another rise usually shaped like a truncated cone but rising more abruptly than it falls.

This epidemic rise in the autumn is extremely characteristic of death returns from the Punjab. It is seen in the death curve of almost every town and thana except in those exceptionally situated in desert regions such as the Thal ; in charts of most places scarcely a year is seen which does not show it to a greater or less extent (*vide* Chart 1).[1] Examining the records it is rare that any other cause than "fever" can be found to account for it and even if other epidemic diseases are prevalent their incidence is out of all proportion to the immense mass of deaths ascribed to fever. If we examine the curve as shown at different places we shall see that it varies very greatly in height and that it is highest as a rule in those places noted for malaria. Again if year by year in any particular place we follow the variations in the height of the autumnal epidemic rises we shall see that they are highest in the years noted as most malarious.

When well developed the autumn epidemic rise exhibits very specific characters, it rises abruptly in September, maintains its greatest height through October and November and sinks rapidly to December and through January to normal. In years in which the rise is small the curve is often more acutely pointed and may be delayed so that the highest point is reached in November or even in December,

[1] All the maps and charts illustrating this report will be found in a pocket attached to the back cover.

this type of curve being especially seen in the records of the extreme north-west where rainfall is most scanty.

As a rule the curve is not interfered with or obscured by those of other epidemic diseases. Sometimes its origin is hidden by a late cholera rise and sometimes its fall is merged in the commencement of the effects of plague, (*vide* Chart 1), but as a rule it stands clear as a very definite and characteristic epidemic rise. It is not a normal constituent of the death curve as in some years it is entirely absent.

We can then divide our fever deaths into (*a*) those returned along with other causes of deaths going to form the ordinary normal mortality and (*b*) those which are recorded during and which go to form the epidemic rise we have been considering. Normally in the Punjab the former class number about 30,000 per mensem. What proportion of these deaths returned as fever are really due to malaria cannot at present even be guessed at. The term "fever" being only the diagnosis of the friend of the deceased or of the village chowkidar cannot be taken as at all necessarily indicating "malaria." In fact the term obviously includes not only all febrile diseases but a great host of deaths returned as fever for want of a better name.

The latter class which we can ascribe entirely to the direct or indirect effects of some epidemic disease prevalent during the months of October and November may in an unhealthy year reach a total of 300,000 deaths or a figure about equal to the total annual fever mortality under normal conditions.

Popularly the increase of sickness and death at times when this curve is high is attributed without hesitation to malaria.

However inaccurate the diagnosis of "fever" may be there is no doubt that excluding plague which has affected the Punjab very severely in recent years, the occurrence of a very healthy or a very unhealthy year as judged by total mortality returns depends almost entirely upon the excess of deaths from "fevers" which has gone to form the autumnal epidemic rise.

Whether any of the rises in the early parts of the year are due to malaria we cannot yet say. But if they are it will be clear from the charts given that as a rule these rises are insignificant in comparison with the extraordinary rise occurring almost every year from "fevers" in the autumn.

We may content ourselves here by pointing out that in the case of the autumnal epidemic rise malaria, if it be malaria, is exhibiting its effects upon the mortality curve as an epidemic disease.

PART II.

AUTUMNAL EPIDEMIC (FULMINANT) MALARIA.

CHAPTER III.

The Epidemic of 1908.

The autumn of 1908 in the Punjab was characterised by an epidemic of extraordinary severity. The effects of this epidemic were first prominently brought before the public by a sudden disorganisation of the train service due to "fever" among the employees at the large railway centre, Lahore. With equal suddenness it made its presence felt throughout the whole Punjab. Where the epidemic was severely felt almost the entire population seems to have been prostrated by sickness ; and the mortality almost invariably rose in such places to a rate of several hundreds per mille.

A very peculiar feature of the epidemic was that though it was severely felt in the rural areas (the returns for the Gurgaon district for example showing among a population of 687,199 a death rate during October of 267 per mille), it seemed to reach its greatest intensity in certain of the towns and very severely affected even the larger cities.

At Amritsar, a city of 160,000 inhabitants, it is stated that almost the entire population was prostrated and the ordinary business of the city interrupted. For many weeks labour for any purpose was unprocurable and even food vendors ceased to carry on their trade. Thus not only was ordinary food difficult to obtain and the prices excessive, but, owing to malaria among the cowkeeper class, milk, a necessity for the very young and the sick, was practically unprocurable even at the exorbitant rate of 8 to 12 annas per seer.

In the two months, October and November, during which the epidemic was at its highest, 307,316 deaths were recorded in the Punjab. In Amritsar the mortality for many weeks was at the rate of over 200 per mille. In Palwal mortality rose to 420 per mille and in Bhera to 493 per mille. Curiously enough in Delhi, a notoriously malarious town, the death rate rose only to 149 per mille. But a closer examination of the statistics shows that parts of the city were much more seriously affected than one would judge to be the case from the statistics for the whole city ; in Ward I, for instance, the mortality rose to over 300 per mille.

In the rural returns the mortality rates were not as a rule so high as those given for badly affected towns. This might be taken as showing that the mortality was greater in towns than in rural areas, but a study of returns from individual thanas and villages modifies this conclusion, many villages and even whole thanas showing mortality rates during October and November of 300—400 or even 500 per mille.

When I first commenced the study of this epidemic I was under the impression that the conditions during this year were quite exceptional. This belief I am inclined to think was general. The severity of the epidemic led many to doubt its malarial nature and even when the probability of its being malaria was allowed the admission was generally held to signify that some special peculiarity was to be expected in the type of malaria present or in the mosquito which transmitted it.

In the course of my investigation it will I think be clear why I no longer look upon the outbreak of 1908 as unique or as likely to be due to causes new to the Punjab.

(i) Sickness.

At Amritsar an examination of the out-patient returns at the hospital showed an increase in total admissions in September from an average of about 400 to 800 and 900 per week. The cause of this increase is entirely due to the extra number of cases entered under malarial fevers, which rose from a number never exceeding one hundred per week to 566 in the 3rd week in October.

In the months of February to April there is an increase noted in the numbers of cases attending for disease of the spleen (enlarged spleen).

The city dispensary returns for the years 1900 to 1908 are as follows :—

Admissions for Malarial Fever and Enlarged Spleen at the Amritsar City Dispensary.

	1900	1901	1902	1903	1904	1905	1906	1907	1908
January . .	71	214	143	87	289	81	82	104	96
February . .	71	123	111	103	203	65	41	77	78
March . . .	143	177	141	113	188	129	81	108	115
April . . .	121	182	161	194	238	147	206	147	123
May . . .	128	221	191	133	240	197	129	146	124
June . . .	98	222	141	128	210	176	139	178	134
July . . .	99	249	163	121	200	156	116	123	139
August . . .	127	319	218	94	186	292	119	182	255
September . .	486	758	246	309	309	262	200	248	2,309
October . .	1,032	1,336	266	1,311	306	218	395	243	3,668
November . .	903	560	167	1,465	199	197	397	206	1,534
December . .	515	298	997	569	173	131	227	150	809
TOTAL .	3,794	4,670	2,960	4,628	2,768	2,055	2,141	1,927	9,396

At Bhera dispensary the weekly admissions for malarial fevers rose from a number never exceeding 50 to over 500 (*vide* Chart 2). Towards the end of the epidemic most of the excess in admissions was due to cases attending for enlargement of the spleen. At Miani the number of admissions for malaria rose from under 50 per week to nearly 700 per week.

(ii) Mortality.

The nature of the mortality curves for different areas will be apparent from Chart 3.[1] They show a sharp rise usually towards the end of September, a high level maintained throughout October and part or the whole of November and rates falling rapidly in December and January to normal. The resemblance of the curve to that of the autumn epidemics previously referred to will be apparent.

It is remarkable that with the exception of the extreme south-east, where the characteristic rise from mortality took place about a fortnight earlier than in the northern part of the Punjab, places even hundreds of miles apart were affected simultaneously.

A comparison of the mortality curve with the dispensary records shows that the two curves follow one another very closely. In the case of Amritsar the admissions first began to be affected towards the end of August, but were not seriously increased until the second week in September ; the deaths were first markedly increased in the fourth week in September. In the case of admissions for sickness the numbers rose to its maximum in the week ending the 3rd October and then declined rather rapidly. The death rate was highest in the week ending 17th October. But the numbers of deaths continued comparatively much higher than the admissions for sickness and did not decline until the end of November, or about a month later than the fall in sickness rates.

At Bhera the first indication of an increase of sickness occurred in the fourth week in August ; the first indication of an increase of mortality was in the middle of September. The admissions were highest in the first week of October and mortality in the third week.

At Miani sickness and mortality appeared almost coincidently, but the admissions rose to their highest point in the last week of September, whilst the greatest mortality was in the second week in October.

In the case of Bhera a second rise in the number of admissions occurred independently of increased mortality reaching its maximum at the end of November. In this town therefore the sickness outlasted the mortality (*vide* next section).

Roughly speaking the increase of mortality followed the increase in sickness by about a fortnight.

---

[1] It will be found in a pocket at the end of the Memoir.

Age composition of mortality.

At Amritsar deaths are recorded by the return to a Registrar of the permits given to persons burying relations in the cemeteries. The system, so far as I have been able to judge, is conscientiously carried out; and the fact that the city is so densely populated makes it improbable that many burials take place except in the cemeteries. During the epidemic over 10,000 deaths were recorded of which we may calculate more than 7,000 must have been directly due to the epidemic.

With such an opportunity it seemed desirable to make a study of the age incidence and distribution of these deaths. Particulars regarding each death were recorded upon a slip and the results of various sortings noted. Results which refer more especially to the distribution of the mortality in different parts of the city will be referred to later when the conditions at Amritsar are discussed. For the present I shall confine myself to the more general features of the epidemic mortality as shown in the analysis of 10,202 deaths investigated.

Separating the total deaths under their respective recorded ages the general nature of the mortality is evident.

Stillbirths		568
Children under one year	1,389	
Children over one year and under two . .	1,253	
„ „ two years „ „ three . .	958	4,528
„ „ three „ „ „ four . .	576	
„ „ four „ „ „ five . .	352	
„ „ five „ „ „ ten . .		795
„ „ ten „ „ „ fifteen . .		310
Persons aged 15 to 20		225
„ „ 20 „ 30		518
„ „ 30 „ 40		403
„ „ 40 „ 50		502
„ „ 50 „ 60		605
Persons over 60		1,748

Of the 10,202 deaths at Amritsar during the epidemic 5,273 deaths were therefore in children under 5 years of age, as against 4,929 for all other ages; 1,748 or another 17 per cent. were in persons 60 years and over.

The plotting out of these figures gives the curve shown in Chart 4. Taking into consideration the fact that the recording of ages must be open to many fallacies the regular nature of the curve is very remarkable and suggests that registration of ages is more accurate than one has suspected. The age composition of the Amritsar population being given in the Census the actuals recorded above were educed to rates per mille for each age, the curve made by these figures being shown by the dotted line on the chart. The epidemic mortality though greater in degree therefore shows the same general incidence as does the normal mortality.

In so severe an epidemic mortality it is surprising to find so few distinctive features one can ascribe to the disease, the ratios suggesting only a great exaggeration of normal stress.

But though at first sight the curve of deaths at Amritsar seems merely an exaggeration of the normal, it will be seen, comparing the epidemic with the normal figures taken from the Census of 1901, that the increase is not really proportionate at all ages. The deaths among children under 1 year for example in the epidemic increased only from the normal 206 to 412, whereas at the age of 5 the increase was from 41 to 356 and at the age of from 5 to 10 years from 13 to 65.

Working out the different increases in the form of a percentage increase curve, it is seen that there is a greater *relative* increase at two years of age than at any other time and that this effect lasts to about the age of 10.

The best demonstration of the differences between the two curves is given by representing in terms of the standard deviations for each series the increase or decrease of the abnormal over the normal mortality at the different ages (*vide* Chart 4).

Or the effect is very remarkably brought out by simply dividing the number of deaths at any age which normally occur into the number recorded during the epidemic (*vide* also Chart 2). In each case the sudden drop in the curve which occurs at about the age of 10 is very noticeable.

At Palwal 680 out of 1,057 deaths were in children under 10, and 304 of these deaths were in infants one year of age and under. Analysis of the curve showed the same relative increase of effect upon childhood as against infancy as noted above.

At Bhera 537 out of 703 deaths were in children under 10, and deaths in infants one year of age and under numbered 260. In 1,014 deaths among villages around Bhera, 832 were in children under 10 and 373 in infants one year and under.

As a matter of interest at Bhera and some other affected places the recorded deaths for the first year of life were divided into months; the result is very remarkable.

	Month.											
	0	1	2	3	4	5	6	7	8	9	10	11
Bhera villages .	49	22	43	38	25	23	31	13	16	15	27	11
Bhera town. .	29	17	19	11	20	18	16	15	17	11	13	5
Amritsar malarious portions . .	72	6	64	57	39	26	45	20	31	28	20	19
Amritsar Central portions . .	54	16	32	9	13	13	14	7	15	10	8	8
Amritsar central non-epidemic portions . .	26	6	6	4	2	3	6	1	6	7	4	5

It will thus be seen that the epidemic mortality has very definite characters.

Following the weekly deaths at Amritsar for each age separately the curve for children under two years was found to rise almost sheer reaching its maximum in the second and third week of October, but at once falling rapidly. The curve of children under 10 rises more slowly and reaches its maximum in the first week in November. The curve of adult deaths rises still more gradually and reaches its maximum only in the last week in November. The curve of old people resembles that of children under 10.

Looking at the curve shown by deaths in Amritsar it will be clear that its conformation is largely due to the facts we have described. The first rush upwards of the line and the first peak is largely due to the sudden mortality amongst infants and young children, the second peak is due to the increasing deaths amongst adults together with the continuance of high death rate among children under 10. Between the two peaks is a notch which is always shown in the figures for different parts of Amritsar city. A similar notch is seen in the curves for Delhi and Palwal.

At Bhera and Miani where adult mortality was low the second peak or hump is not apparent, nor is the same breadth of the curve visible. Both characters are seen, however, in the curves for Sonepat, Mehrauli and Jhelum. At Palwal the second peak due, as at Amritsar to deaths among adults reaching their maximum later than did those among infants, is even higher than the first.

Stillbirths.

Associated with the increased mortality at Amritsar was an extraordinary increase in deaths returned as "stillborn." The increase was so great, reaching, in the four months September to December, the figure of 568, that it must be considered part of the effect of the epidemic. Since the records come from the cemeteries the term stillbirth could scarcely have been applied to any condition other than a birth within the last three months of pregnancy or to children dying within the first day or so of birth. We may (in order to see the significance of the figures and allowing a latitude greater than we have indicated) consider that deaths recorded as stillbirths represent deaths in the fœtus during the last six months of uterine life. In this case the number for a year would be 1,136 or nearly as high a rate as occurred amongst children *after* birth. If stillbirths were taken as representing the mortality among fœtuses three months or less prior to birth, the rate would almost continue the curve of mortality into the prenatal condition.

The distribution of stillbirths also does not follow that of the adult mortality, but reaches its greatest height at the same period as deaths among children under two years.

At Bhera and other places stillbirths were not recorded in such numbers, but it is quite possible the conditions were not so favourable as at Amritsar for the record of such occurrences.

(iii) Spleen Rate.

In Chapters VI to VII will be considered in detail the conditions at those places actually visited ; but a summary of the observations upon splenic enlargement and parasite rate seems desirable whilst discussing the general characters of the epidemic.

In order to give more information than is given by merely quoting the total percentage of children with enlarged spleens I have adopted for the record of spleen rate five classes, namely, (1) very large spleens reaching to the umbilicus or beyond ; (2) spleens four fingers' or a hand's breadth below the costal margin or approximately 7-10 cm. ; (3) spleens two or three fingers' breadth below the costal margin or approximately 2-7 cm. ; (4) spleens only palpable or a finger's breadth below the costal margin (2 cm.) ; (5) spleens not palpable. In this paper are given the percentages of these five classes always in the same order, namely, from left to right, class I, II, III, IV, V. Following these is given the total percentage of children with enlarged spleens, and last of all the numbers of children examined.

Immediately after the epidemic (February to April) the spleen rate in percentages of those places visited was as follows :—

	Class I.	Class II.	Class III.	Class IV.	Class V.	Total.	No. of children.
Amritsar town	1·6	7·7	31·5	24·5	34·6	63·4%	1,253
Amritsar villages	4	10	43	29	13	87 %	122
Palwal town	4	15	49	19	12	88 %	147
Palwal villages	3	16	50	20	18	82 %	133
Delhi	2	8	30	22	38	62 %	279

The splenic rate observed in different areas of Amritsar and the mortality rates recorded in the areas during the epidemic are as noted below:—

	Population.	Rate per mille Oct. and Nov.							
Division 9 . . .	17,206	448	3	12	40	24	19	81%	418
Division 4 . . .	5,460	117	0	0	4	10	86	14%	112
Division 6 . . .	8,335	80							
Division 8 . . .	13,553	328	0	1	28	12	58	42%	178
Divisions 5 and 7 . .	42,048	375	1	11	42	29	16	84%	256

At Delhi a sub-division of the figures into those relating to the badly affected Wards 4, 5, and 11 lying towards the river Jumna and those relating to the comparatively slightly affected wards on the west of the city gives :—

Wards 4, 5, 11	4	18	41	16	19	81%	114
Wards 6, 7, 9	5	2	29	19	49	51%	165

Later in the year (July) the following places were visited, the spleen rate being as below :—

Bhera town	1	13	47	23	16	84%	113
Bhera villages	2	12	51	24	10	90%	227
Miani	5	18	35	19	21	79%	56
Gujrat town	2	2	17	22	57	43%	57
Gujrat villages (Slightly affected.)	0	0	15	20	65	35%	73
Gujrat villages (Severely affected.)	1	17	35	14	32	68%	69

All the above areas were badly affected by the epidemic. Bhera town and tract were both profoundly affected ; Miani only slightly less so. Gujrat town showed a mortality reaching a maximum of 247 per mille. In the case of the Gujrat villages some were profoundly affected by the epidemic, in others the mortality was not so great. It will be seen that the spleen rate is highest in the former.

In the Shahpur District there were areas in which, judging from the mortality, the epidemic had been very mild or had even in some cases not effected the death rate (Kot Momon). The following are the spleen rates in the district :—

Badly affected	Wegowal, Dharema, Kandan	1	11	23	19	45	55%	69
Moderately affected	Akelgahr, Shahpur, Nathowal	0	4	32	18	46	54%	98
Unaffected or very slightly affected.	Bhalwal and Kot Momon villages.	0	1	10	13	74	26%	67

The spleen rate therefore shows a very distinct relation to the mortality.

Parasite rate.

At Amritsar immediately after the epidemic (February) the relation of parasites to spleen rate was as follows :—

	Spleen rate.	Parasite rate.
Lakar Mandi, Mahan Singh	90	66
Subanian	66	58
Chauk Pasian 1	13	20
Chauk Pasian 2	37	34
Hati Gate	47	50
Kanyan 1	37	43
Kanyan 2	54	50
Hakuman	93	72

At other places examined at this time the relations were as below:—

	Spleen rate.	Parasite rate.
Atari	80	35
Palwal	88	83
Dhatir	75	30

There is thus every reason to believe that the enlargement of the spleen noted is in the main the effect of malaria. In Delhi a number of very large spleens were punctured during life and at Amritsar spleen smears were obtained from the cadaver ; but in none were the parasites of Kala Azar found. Major James, I.M.S., has similarly failed to find in the Punjab evidence of Kala Azar. This disease is scarcely likely therefore to interfere seriously with the use of the spleen test for malaria.

The types of parasite found at the different places visited were as follows:—

	Simple tertian.	Malignant tertian.	Quartan.
Amritsar	Present.	Present.	Present.
Delhi	„	„	„
Palwal	„	„	0
Dhatir	„	„	0
Atari	„	„	0
Gujrat	„	„	0
Dhera	„	0	0
Shahpur	„	0	0

There was therefore so far as one could see no new form of parasite concerned. Without seeing the conditions during the epidemic it would be rash to say whether one or the other of the known forms of the parasite were especially concerned or not. But the fact that almost immediately after the epidemic all three forms, and especially the two commoner species, tropical and simple tertian, were found in the blood of the children at Amritsar does not suggest any one parasite being specially concerned.

(iv) Nature of the Epidemic.

We have already given sufficient evidence to remove any doubt as to the true nature of the epidemic.

It exhibited the well known incidence of the ordinary autumnal fever of the Punjab corresponding with the prevalence of malarial parasites, as shown by the observations of Dr. Stephens, Major James and myself, among the natives of Mian Mir, and by ourselves and others in European soldiers in cantonments. It was

accompanied everywhere by an increase in dispensary admissions for what was clinically malaria; it was also followed in every case where the subject was enquired into by a noticeable increase in the numbers of people attending hospital for splenic enlargement.

The greatest incidence of mortality was amongst infants and the study of mortality at Amritsar demonstrates a very peculiar coincidence between the greatest relative increase of mortality and the periods of life known to be most subject to malarial infection.

Examination shortly after the epidemic of areas especially affected shows in every instance a remarkable condition of almost universal infection with malaria. In Palwal and the affected areas of Amritsar almost every child had splenic enlargement and malarial parasites in the blood. In Bhera and in the villages of the Bhera thana the same condition prevailed.

When, as in the thanas of Bhalwal and Kot Momon in the Shahpur District, an area but little affected by the epidemic is examined the spleen rate is low. The same thing holds good for parts of Amritsar and Delhi that were comparatively little affected. Lastly, the enlargement of spleen found so universally is accompanied by a proportionate prevalence of malaria parasites; and these are of the ordinary well known varieties.

Later in the report the malarial nature of the epidemic and its relation to the ordinary malaria of the district will be even more apparent.

CHAPTER IV.

The Distribution of the Epidemic of 1908.

The epidemic affected to greater or less extent almost the whole of the central and eastern Punjab. In the returns for towns a marked rise in deaths in the months of October and November was almost universal. Almost all the districts also show some increase in the death rates, those most seriously affected being Gurgaon and Gujrat.

A detailed and very instructive picture of the distribution of the mortality is that obtained by a method which I have described in a paper previously referred to. In this I have explained how it is possible with considerable accuracy to map out both the area affected by an epidemic and the epidemic intensity at different places.

The figures which have enabled me to do this in the present instance were very kindly supplied to me by the Sanitary Commissioner of the Punjab. In mapping the conditions I have employed for the epidemic rate the total deaths in October, the epidemic in almost every case being at its highest in this month. The average non-epidemic rate I have obtained by averaging the deaths in June and July for five years, avoiding those years in which plague or cholera disturbed the figures. Throughout I have employed the thanas as units.

As an example of the extraordinary increases in the death rate with which we are dealing and to show how comparatively little slight inaccuracy would affect the general results, the reader may refer to Chapter VII where a number of examples are given.

The result of mapping out the epidemic of 1908 in this way is shown in Map I.[1] In preparing this map I have placed opposite the name of each thana the epidemic figure relating to it and then drawn lines of equi-mortality through these. The figures have been omitted in the final copy of the map for the sake of clearness, colours only being used to express intensity.

Mapping out in this way the extreme limit of distribution of the epidemic, its area would be very great, but limiting our attention to those places affected by a death rate over five times the normal we get the picture shown on the accompanying map. Two large epidemic areas are shown, one on the north involving Gujrat, Gujranwala and Shahpur, and one in the south-east involving Gurgaon, Delhi and parts of Rohtak Districts which were evidently the seat of great epidemic intensity. Other smaller epidemic centres are shown, notably one over Ludhiana and part of Jullunder; but in comparison with the two large areas noted these are small in area and low in intensity.

---

[1] It will be found in a pocket at the end of the Memoir. The three shades of red indicate in order of intensity a death rate during October of five, seven and ten times the normal respectively. The three shades of blue indicate in order of intensity a rainfall during June to September of over ten, over twenty, and over thirty inches respectively.

CHAPTER IV.

The Distribution of the Epidemic of 1908.

The epidemic affected to greater or less extent almost the whole of the central and eastern Punjab. In the returns for towns a marked rise in deaths in the months of October and November was almost universal. Almost all the districts also show some increase in the death rates, those most seriously affected being Gurgaon and Gujrat.

A detailed and very instructive picture of the distribution of the mortality is that obtained by a method which I have described in a paper previously referred to. In this I have explained how it is possible with considerable accuracy to map out both the area affected by an epidemic and the epidemic intensity at different places.

The figures which have enabled me to do this in the present instance were very kindly supplied to me by the Sanitary Commissioner of the Punjab. In mapping the conditions I have employed for the epidemic rate the total deaths in October, the epidemic in almost every case being at its highest in this month. The average non-epidemic rate I have obtained by averaging the deaths in June and July for five years, avoiding those years in which plague or cholera disturbed the figures. Throughout I have employed the thanas as units.

As an example of the extraordinary increases in the death rate with which we are dealing and to show how comparatively little slight inaccuracy would affect the general results, the reader may refer to Chapter VII where a number of examples are given.

The result of mapping out the epidemic of 1908 in this way is shown in Map I.[1] In preparing this map I have placed opposite the name of each thana the epidemic figure relating to it and then drawn lines of equi-mortality through these. The figures have been omitted in the final copy of the map for the sake of clearness, colours only being used to express intensity.

Mapping out in this way the extreme limit of distribution of the epidemic, its area would be very great, but limiting our attention to those places affected by a death rate over five times the normal we get the picture shown on the accompanying map. Two large epidemic areas are shown, one on the north involving Gujrat, Gujranwala and Shahpur, and one in the south-east involving Gurgaon, Delhi and parts of Rohtak Districts which were evidently the seat of great epidemic intensity. Other smaller epidemic centres are shown, notably one over Ludhiana and part of Jullunder; but in comparison with the two large areas noted these are small in area and low in intensity.

---

[1] It will be found in a pocket at the end of the Memoir. The three shades of red indicate in order of intensity a death rate during October of five, seven and ten times the normal respectively. The three shades of blue indicate in order of intensity a rainfall during June to September of over ten, over twenty, and over thirty inches respectively.

These areas are clearly not chance effects, for they show not only a clearly defined affected tract but exhibit a regular increase of epidemic intensity as we pass from the periphery to the centre of the area.

Had the malaria of 1908 depended on merely local causes, the number of pools about a village and so on, we should have expected to obtain a map covered with confused figures indicating haphazard variations, as the intensity of the disease rose or fell from thana to thana. There would be no reason why numbers of severely affected thanas should form as it were a nucleus to epidemic areas or that the intensity of the disease should show a more or less regular decline as we pass outwards from these foci.

I am not aware that these features have ever been demonstrated in regard to malaria ; and the map alone is sufficient to show that there was in the epidemic of 1908 some general determining influence over and above merely local conditions which acted much as an area of low or high atmospheric pressure might have acted, supposing this to affect the mortality.

Turning to a study of the details shown by the map we cannot fail to be struck by the fact that a very noticeable feature, especially of the northern area, is the occurrence of certain tongues of epidemic, and it will be clear that these tend to be associated with certain of the larger rivers.

To the north the northern area is limited by the mountains and in the east it seems to have avoided Gurdaspur ; but on the west it extends in great intensity along the Jhelum river to end somewhere in the neighbourhood of Shahpur. The tract of land between the rivers Jhelum and Chenab is comparatively unaffected, but in the neighbourhood of the Chenab river another great tongue of the epidemic extends in a south-westerly direction. Again passing southwards the inter-riverain tract is unaffected ; but we come to a third tongue lying broadly speaking over the Ravi. This tongue is continued by two isolated patches further down the river at Kamalia and Tolumba.

To the south of this tongue there is a broad patch of epidemic which would appear from the map not to be associated with any river, but which is in reality associated with a deserted riverain of the Beas, which river formerly ran through Kasur and the Montgomery District. Two spots of epidemic intensity are seen in connection with the Sutlej riverain, but otherwise this tract is unaffected.

The southern area does not show in the Punjab any particular epidemic tongues, though as a matter of fact, as we shall find later, this area is only partly represented within the confines of the Punjab. A distinct association of an epidemic area with a river is shown at Ellenabad and Jamal below Sirsa where the river Ghagger ends blindly. Other spots are shown at Mailsi and Mitro, in this case to the side of, but extending away from, the Sutlej and on the banks

of the Indus where this river first debouches from the hills in the north of the Mianwali District. A tract occupying part of Ludhiana and extending up between the Hoshiapur and Jullunder Districts, will be observed to lie across, but not to extend along, the Sutlej valley.

But though the fringes of the epidemic show a relation to rivers, etc., the main epidemic areas show comparatively little relation to any physical features and affect without exception the thanas over a very wide extent of country.

The conditions in such areas are altogether extraordinary. In the northern epidemic area throughout a tract covering a great part of Gujrat, half of Gujranwala and a part of the Lahore District, there is not a thana in which the death rate for the month of October did not rise over seven times the normal rate, whilst the death rate for the thana of Gujrat itself was eleven times greater than the normal; and if we can credit the figures there are villages in the Gujrat thana showing in some cases a mortality as much as thirty times the normal.

In the special focus at Bhera there are scarcely any villages showing a death rate below 200 per mille, whilst the majority ranged between 200 and 400, and one shows the extraordinary figure of 641 per mille.

If it were not for Bhera town itself, which shows an equally high mortality rate, we should hesitate to credit these extraordinary values. Yet if there be errors of registration, one would think they must err on the side of underestimating rather than overestimating the mortality.

In the southern area scarcely a thana south of Delhi had a death rate under seven times the normal, whilst again there are areas in the centre of the epidemic area which have been even more severely affected, the rates varying from ten to seventeen times the normal.

In the thana of Nuh for example, where there normally are about 125 deaths in the month, there occurred in October 1908 no less than 1,404 deaths. In the thana of Hodal, which normally has about 100 deaths, there occurred in October 1,083 deaths. In the thana of Ferozepore, with a normal of 130 deaths per month, there occurred 2,346 deaths.

In the case of the southern area the nucleus is almost coincident with the Gurgaon District. The population of the Gurgaon District is nearly three-quarters of a million. In October the recorded death rate per mille was 267. This being the average of all villages in the district, it is more than probable that many of them must have had rates much higher. As a rule the maximum intensity reached by the mortality in 1908 was about 400 per mille. Such effects are not seen elsewhere than within the circumscribed zone of an epidemic nucleus.

In the case of towns if we refer to the figures we shall see that those situated in areas of special intensity suffered most severely in the epidemic of 1908.

The following list of towns with the rate per mille for the last week in October is taken from the returns published in the *Punjab Gazette*. Opposite to them is placed the epidemic figure for the thana in which the town is situated :—

Town and thana rates, proportionate.			Town rates high in proportion to thana rates.			Town rates low in proportion to thana rates.		
	High.							
Bhera	18·1	493	Hansi	4·5	162	Jhagger	11·6	108
Palwal	9·5	408	Bhiwani	4	110	Rewari	6·7	32
Hodal	9·6	500	Karnal	3·9	104	Gujranwala	6·7	86
Amritsar	9·7	308	Jagadri	2·8	97	Jalalpur	8·6	128
Sonepat	7·7	238	Hoshapur	4·9	100	Jhelum	9	121
P. D. Khan	19	207	Tanda Urmar	5·3	153	Gujrat	11·1	151
Bhiwani	6	110	Kasur	3·6	140			
Rohtak	7·6	108	Jhang	4·3	152			
Wazirabad	7·6	174						
Chiniot	8	163						
	Low.							
Batala	2·9	65						
Umballa	3·6	39						
Jullunder	3·3	50						
Kartarpur	4·1	43						
Ludhiana	5·7	67						
Jagraon	4·5	78						
Ferozepore	3·7	76						
Sialkot	4·8	88						
Hissar	5·5	57						
Kaital	3·6	70						
Rawalpindi	2	56						
Multan	3	87						
D. G. Khan	4	61						

Epidemic distribution beyond the borders of the Punjab.

A description of the distribution of the epidemic would not be complete without a reference to conditions beyond the borders of the Punjab.

Though no extension northwards of the epidemic is shown beyond the Jhelum District there were areas in Rawalpindi and Attock which were just too low to be included in the line representing the epidemic figure of 5. Had a line representing three times the normal death rate been taken, considerable areas in these districts would have been shown as affected.

The most important extension of epidemic conditions beyond the limits of the Punjab was into the United Provinces. I have had no opportunity to study the figures in detail relating to the epidemic distribution in these parts : but an examination of the monthly district figures given in the report of the Provincial Sanitary Commissioner enables me to indicate the main distribution sufficiently in detail for our purpose. The two worst affected districts appear to have been Muttra and Agra which show for the whole district an epidemic figure in each case of about 7. These districts lie to the south-east of Gurgaon and thus the epidemic conditions are continued in great intensity down the valley of the Jumna. The other districts most seriously affected are Bulandshahr; Alighar and Budaon, all of which lie grouped around the first two mentioned districts, thus forming the nucleus of a large epidemic area. Around these again lies a belt of less seriously affected districts, the epidemic figures of which grow less until they approach unity at a line, roughly speaking, which passes through the centre of the Province from north to south. East of this line most of the districts are unaffected.

The epidemic which in 1908 affected the United Provinces was therefore the eastern half of the southern epidemic we have already studied in the Punjab.

What the extension of this area to the south in the Central India Agency or what the conditions were in Sindh, I have no information to enable me to say.

CHAPTER V.

Previous Epidemics in the Punjab.

As already stated when I commenced the study of the epidemic of 1908 I was under the impression that I had to deal with some newly introduced condition. But on studying the records I was surprised to find that not only had there been similar epidemics in the past, but that several of these were scarcely inferior in their effects to the epidemic of 1908. Also when these were mapped out they showed very strikingly the localised nature of the epidemic area and the peculiar increase of intensity as the nucleus was approached which enables one to map out these Punjab epidemics as one might do the varying levels of land by contour lines or the differences of atmospheric pressure by isobars.

The first epidemic for which we have mortality figures occurred in 1869 (*vide* Chart 5). As detailed figures are not available I have not been able to map out its distribution. The number of deaths recorded from fever in October and November was 116,540 ; though at this time registration was less accurate than it has been in late years.

The years 1870, 1872 and 1875 show rather high fever figures, but the first great rise in mortality occurs in 1876, the recorded deaths from fever in October and November in this year being 174,238.

The epidemic responsible for this rise in the mortality when mapped out is seen to be a much less diffused area than that of 1908 and large tracts in the Punjab are quite unaffected. The greatest intensity of the epidemic in this case is over Sialkot, Gurdaspur and parts of Hoshiarpur and Jullunder. The tendency to follow rivers is seen at three places (Chenab, Ravi and Sutlej), but there are no such long tongues as in 1908. The death rate over almost the whole of Sialkot, Gurdaspur and Hoshiarpur was over seven times the normal, whilst in the nucleus of the epidemic there are epidemic figures as high as 20.

In 1878 there is an epidemic affecting chiefly Ludhiana, Jullunder and Hoshiarpur. The extreme limits of the epidemic do not extend beyond a line bisecting the Punjab from north to south ; and the chief severity is confined to a comparatively small area. The main epidemic area lay in the neighbourhood of the Sutlej, but the epidemic shewed a peculiar extension along the north of the Amritsar District with a special focus about Batala. A slight degree of increased mortality also formed tongues along the three rivers—the Jhelum, the Chenab and the Ravi—much as happened in the epidemic of 1908. There was also a spot of epidemic intensity at Bhera and some small areas in Gurgaon, Delhi and Rohtak. The number of deaths recorded in the months of October and November in this year was 180,356.

The following year, 1879, another epidemic, confined to the extreme south, attacked the Punjab. The main effects of this epidemic were seen over Hissar and parts of the Gurgaon District, the nucleus of the epidemic being very large, though the effects of the epidemic as a whole were circumscribed. A spot of epidemic intensity is seen over Ellenabad, Rania and Sirsa. The thanas Indri, Butana, Nisang are also seen to be affected to some extent. The deaths in this year in the months of October and November, in spite of the circumscribed area affected and the defective registration, numbered 141,996.

In 1884 we have an epidemic area over Ludhiana and Umballa with a nucleus characterised by very high figures, the thana of Machiwara showing 30 times the normal death rate, whilst several thanas are 18 and 19 times the normal. There are also three curious small isolated areas of high intensity, one in the low-lying area of Thanda Urmar stretching northwards to Gurdaspur, one near Delhi and one in the Sutlej riverain near Ferozepore. A peculiar tongue of epidemic lies along the Jumna riverain in the Karnal District.

Again a spot of epidemic is to be seen at Ellenabad. The extreme limits of the epidemic as shown by an epidemic figure of two or over do not extend as far west as the Montgomery District.

In the years 1887 and 1889 there was a raised mortality, but I have not traced out the epidemic distribution.

In 1890 we have an extraordinarily compact epidemic with an enormous nucleus involving Sialkot, parts of Gujrat and Gujranwala, characterised by terrible mortality rates, Wazirabad having an epidemic figure of 28, Sialkot of 26 and Gujrat of 24.

In this year the deaths numbered 246,487 in spite of the fact that large portions of the southern and western Punjab was unaffected.

In 1892 there is again an epidemic area of enromous size, *vide* large map (Map II). This year in fact is one remembered as the great fever year. But in spite of the enormous nucleus extending over several whole districts there was in the southern Punjab no trace of an epidemic. The death rates indeed for most of the thanas in Gurgaon, Delhi, Karnal and Rohtak were not raised above their non-epidemic rates. The epidemic in this year extended further west than any previous one and involved almost the whole of the Shahpur District as well as seriously affecting Montgomery and Multan. Its effects were also felt northwards in Rawalpindi and even in Peshawar. Several tongues are seen extending to the south-west and there are some isolated spots of epidemic in the Sutlej riverain and near Sirsa. The deaths in this year numbered 283,223 or only slightly less than the number in 1908.

In 1894 there is a single epidemic area over Gurdaspur, Amritsar, Jullunder and part of Sialkot and Hoshiapur, with a small nucleus to the north of the

Amritsar District and one over Jullunder. The deaths in this year numbered for October and November 132,767.

In 1900 there was a large epidemic over Ludhiana, Umballa and Karnal. To the north over Gurdaspur and Sialkot was another smaller epidemic area with points of special intensity over Gurdaspur and Raya. In the Lahore District is shown a small isolated area of high intensity which lies somewhat north of the Sutlej (old bed of Beas). The deaths in the autumn of this year numbered 254,580 as against 307,316 in 1908. Therefore even so late as 1900 we have a condition very similar to and a mortality not very far short of that in 1908.

The conditions in the year 1908 were therefore in no way new to the Punjab. Even as regards gross mortality this epidemic was but slightly more severe than the epidemic of 1892, and the areas of special intensity were neither so extensive nor so severe as those of some previous years. What seems to have made the year 1908 so noticeable was the fact that epidemic conditions were diffused so generally throughout the Punjab. This year was also the first in which two distinct epidemic areas of large size have been present.

In years not so tremendously characterised by mortality we find that the autumn fever exhibits the same tendency to localisation, but, being smaller in degree and insignificant in area, such epidemics do not influence the general statistics as do the great ones we have just described. In other years there are no epidemic areas.

For want of time I have attempted to trace out a few recent years only ; 1906 is an example of a year with small epidemics ; 1903 also shows incipient epidemic areas ; 1904 was practically free from any epidemic and it is noticeable that the deaths for October and November are not above the normal non-epidemic rate of about 30,000 per mensem.

These facts show us that in the Punjab we have malaria normally exhibiting itself in a very peculiar and definite way, one of the characters of which is the formation over some part or other of the Punjab of what might almost be called a malaria cyclone.

Later on we shall see that these effects are not due merely to the malaria visiting now and again a population otherwise free from the disease, for, as we shall see later, in years when the mortality is not above normal we still find that anopheles are plentiful, that the prevalence of enlarged spleen is very great and that parasites are found freely in the blood of children and others.

From the characters I have outlined this type of malarial manifestation might well be called "fulminant" malaria, and I shall in future term areas severely affected in this way "fulminant areas."

CHAPTER VI.

Conditions at Amritsar and Other Towns.

(i) Amritsar.

In the epidemic of 1908, Amritsar lost over 10,000 persons or one-sixteenth of its population. Being an important city, a large trade centre and the religious capital of the Sikhs this effect of the epidemic naturally aroused a great deal of attention. That malaria had this effect upon the population of a city (and this a very compactly built one even for the Punjab where the cities as a rule are very compact), and the fact that during the epidemic towns seem to have suffered even more severely than the rural areas, made the investigation of conditions at Amritsar very important.

Amritsar, the population of which in 1901 was 161,039, is situated on the Bari Doab, about midway between the two rivers—the Beas and the Ravi. The Doab, at this part about sixty miles wide, is low lying and heavily irrigated. The city lies in a shallow depression such as I have referred to in the introduction which, though unrecognisable to the unaided eye, acts as a line of drainage. The soil is the usual fine silt but with a good many intercalated beds of sand. The subsoil water lies everywhere very near the surface being at most at a depth of 6½ to 10 feet (June 1910 after a dry season), and in depressed areas during the rains within 3 or 4 feet or less.

The city occupies an oval site about 1½ miles in the longest and 1¼ miles in its shortest diameter. It is a walled city and very compact, the population numbering in parts over 500 to the acre. Even with this density the map will show that all the land within the line of walls is not built over. But there exists a nucleus of densely aggregated town with scarcely a break of any kind and characterised by tall buildings and deep narrow alleys. A surrounding zone of smaller houses less densely aggregated is also almost unbroken, but outside this again there are in parts even considerable areas of waste land and gardens (*vide* Map III).

In my description of the conditions in Amritsar these different zones will frequently be referred to and some brief description of them is necessary. The central nucleus roughly speaking forms an oval lying to the west up against the city wall. From east to west it is not quite ¾ of a mile and from north to south slightly over ¾ of a mile ocross. On the west it is broken by the garden of a hospital and near its centre it has a deserted garden, now a piece of waste ground, and one other quite small patch of the same nature, otherwise this portion of the city has no open spaces ; one or two large tanks in the city we shall see are harmless,

since they do not breed anopheles and are surrounded by the least malarious parts of the town. The main roads are lined with shops and off these open narrow "gullies" which correspond to the slums of European towns, and are often so narrow that two people cannot easily pass one another without stepping aside. In parts there are buildings 4 or 5 stories high massed together, so that the gullies between them are quite dark and gloomy. For the purpose of description this portion of the town will be called the central area.

Along its western side are the densely crowded quarters known as Katras Moti Ram, Lohgohr, Dulu and Chitta Katra. A small portion near the Hospital garden already referred to known as Sant Singh is occupied by sweepers and cowkeepers, and is perhaps more correctly considered a portion of the outer zone. Towards the centre are the crowded Katras Chauk Pasian, and Chowrasta Atara, Churt Singh and Hari Singh. To the east lying in Division 6 are the grain and salt markets. To the south is Killabangian, partly a comparatively well-to-do quarter and partly occupied by cowkeeper class, this latter portion forming as it were a small bay in which the outer zone penetrates further into the centre of Amritsar than usual. A similar bay occurs on the south-east corner (Bhai Busti Ram), and a small island (K. Khai) of high houses occupied by well-to-do Hindus lies to the south of the central area in the Khazana Division (*vide* Map III). These points are all of importance in regard to observations later on upon the mortality and spleen rate.

As one approaches the periphery the tall many storied buildings of the central area give place rather abruptly to buildings one or at most two stories high, usually built of brick with flat mud roofs. So soon as this outer zone is reached, open yards, stables and such like conditions are found, and cowsheds which scarcely exist in the central area are here numerous. The Division known as Kunyan is almost composed of the houses of cowkeepers, whilst large communities of the same class live in Mahan Singh and elsewhere.

As one approaches the walls open spaces are found encroaching upon the city or what evidently have been gardens, now exist as waste land and lie between crowded collections of mud and brick houses. To the south and west the lands are for the most part cultivated or waste, but to the north-east in Jalewalyan many are still kept up as private gardens. In Division 2 what would elsewhere be land of this kind has been made into a Municipal garden.

Though forming what might seem to be the least important portion of the city, this peripheral zone is densely populated and taken collectively its inhabitants equal or exceed the apparently more important central zone. Thus Division 9, which consists wholly of houses such as we have described as forming the outer zone, has a population of 17,206. Division 7, also wholly composed of this class of house, has a population of 12,272, and Division 5 of 10,521.

As far as the arrangement of the Municipal Divisions will allow us we may make the following rough calculation of the number of persons living in the central and peripheral zones respectively :—

Peripheral.		Central.	
Division 9	17,206	Division 4 . . .	5,460
Division 7	12,272	Division 6 . . .	8,335
Division 5	10,521	Division 8 . . .	13,553
Division 3	6,639	Division 10 . . .	18,001
Division 2	12,616	Division 11 . . .	16,748
Division 1	15,796	Division 12 . . .	15,081
Total .	75,050	Total .	77,178

In Jalewalyan and Chowni Nehangen there exist isolated blocks of houses, which might almost be considered as hamlets, being surrounded as they are on all sides by waste ground, gardens, etc., and the conditions in these areas resemble closely those found in villages. The same applies to houses on the extreme outskirts of the city to the south.

The peripheral zone for the most part, however, forms an unbroken extent of city differing from the central zone, chiefly in the fact that the houses are low, that there are many stables and cowsheds and in some parts small or larger compounds. Roughly speaking this zone is about a quarter of a mile wide surrounding the central area on the north, east and south. It comprises four great quarters, Khazana, Gurba Singh, Ramgurian and Mahan Singh, lying roughly to the south-west, south-east, east and north-east, respectively. The first in reality comprises Katras Khazana, Hakiman, Karam Singh, the second Gurba Singh and Ghumarian and the latter Baghian and Mahan Singh, but for our purpose the former names will suffice. The areas spoken of will be seen on the map.

Khazana contairs a large proportion of country people and potters ; it also is a centre of Mahomedan and Kashmiri weavers who carry on their trade to a large extent under petty employers. Gurba Singh is an extraordinarily densely inhabited area occupied by a squalid population of potters, cowkeepers and cultivators. Ramgurian is chiefly remarkable as being largely populated by those who go into the central zone to work under shopkeepers or in the manifold trades carried on in Amritsar. There are also large communities of middle and low class Sikhs who carry on such work as carpentering and a considerable number of Kashmiris. Mahan Singh is a crowded quarter largely occupied by cowkeepers and Kashmiris.

The immediate surroundings of Amritsar appear at first sight as a maze of waste land, excavated tracts and large pools of water, the general features being shown in the accompanying map (Map III). Considered more carefully it can be

made out that between the city and the original surface of the land, for the most part cultivated and bearing crops or lying fallow as the case may be, is an excavated zone in some places a mile in width, from which more or less recently or remotely millions of tons of soil have been excavated. In part these excavated lands are dry, in part covered with water. To the north-east of the city the subsoil level is very high and the appearance is that of a sodden marsh, the land when not covered by water showing saline efflorescence and a stunted unhealthy looking growth of grass.

Around the city lies a drain evidently intended to cut off to some extent the flow of subsoil water from the north-east. This drain in its upper parts is full to the brim of sluggish water covered with *lemna* but flows more swiftly as it passes to the south. Nearer the city is a second drain full of rank vegetation and heavily polluted. It rarely contains larvæ.

When the pools and sheets of water are examined more closely many of them are seen to be so foul with sewage that as regards mosquito larvæ they are quite sterile. Others less polluted and of a vivid green from the growth of blue green algæ serve as breeding places of *chironomus*, but are quite unsuitable for "anopheles" or even "culex."

Previous Epidemics at Amritsar.

The present epidemic is not the first from which the city of Amritsar has suffered, nor even the most severe. The recorded deaths in October 1881 numbered 5,582 or about 1,500 more than they did in October 1908. Epidemic conditions in the Punjab generally were not very severe in this year and even in Amritsar District the mortality bore no relation to that in the city. It seems very probable that the severity of the outbreak was associated with economic conditions affecting the large bodies of Kashmiri workers who about this time were adversely affected by the decay of the shawl trade in Amritsar.

Other epidemic years have been 1876 when deaths in October numbered 2,430, 1878 when there were 1,690 deaths, and the years 1890 and 1892 when, however, deaths in October only numbered 1,254 and 1,663, respectively.

An epidemic, with 10,000 to 12,000 deaths, is also recorded as having occurred in 1867.

Distribution of Epidemic Mortality in Amritsar.

In Chapter III the result of an analysis of the Amritsar deaths has been given according to ages and other general conditions. But the material was also made use of to ascertain the distributions of mortality in the city.

For this purpose Amritsar was divided into 44 areas which represented very roughly about the same population and, so far as could be seen, were homogeneous within themselves.

The slips upon which the locality of the death were recorded were then sorted so as to obtain information regarding the deaths in each of the chosen areas. In noting the final results certain of these areas were massed together, but only such as were found to exhibit no essential differences in regard to mortality.

Unfortunately the only areas in Amritsar for which the population is known (the divisions) lie for the most part radially, so that they include portions of both centre and periphery of the town. Three divisions, however, 4, 6 and 8, are wholly central and six divisions, 1, 2, 3, 5, 6, 7 and 9, are mainly peripheral (*vide* Map III). For the sake of getting rates per mille I have given the figures as they work out for these wards in the different months of the epidemic. For the sake of comparison the mortality of divisions 10, 11, and 12, which lie along the western portion of the town and compose the western half of the central zone, are also given.

	August.	September.	October.	November.	December.
Division 1	37	73	311	235	96
Division 2	40	99	289	204	108
Division 3	52	166	231	142	90
Division 5	67	141	438	277	144
Division 7	81	162	494	289	151
Division 9	70	113	464	434	202
Division 4	15	42	119	116	55
Division 6	9	12	86	75	62
Division 8	71	80	343	315	145
Division 10	37	51	293	192	115
Division 11	54	80	342	250	150
Division 12	76	78	360	290	170

These figures show distinctly that the central parts of the town were less affected than the periphery. But they show also that even the centre was subjected to epidemic conditions. The extent to which the densely populated quarters, Dulu, Lohgarh and so on, which make up Divisions 10 and 11, also suffered is well demonstrated.

For a more detailed survey it has been necessary to employ the methods of using epidemic figures.

Mapped out according to epidemic figures not only is the general distribution of mortality shown, but by using the figures for the different months, August to December, the history of the invasion of the epidemic can be very clearly traced

The results shown are worth some detailed consideration.

In August a raised death rate was already apparent throughout most of the outer portion of peripheral zone (*vide* Map 6). A rate equal to double the normal was also seen in Killabangian cowkeeper quarters already referred to as penetrating like a bay into the southern portion of the central area. In Dulu and the crowded quarters to the west the death rate was not yet raised. The highest epidemic figures are 4 in the squalid and densely crowded Ghumarian quarter and 2·8 in the hamlet zone at Jalewalyan.

In September raised mortality had mapped out by default with great precision the boundaries of the central zone, the only part of this zone affected being the cowkeeper quarters in Killabangian and the strangers quarters near the Golden Temple. The whole peripheral zone, however, showed epidemic figures of 2 or over. At this time the extreme outer portions in several instances (Hakiman, Gurba Singh and Mahan Singh) had figures of over 3, and the figures for the two areas, Ghumarian and Jalewalyan, reached 6·5 and 8·8, respectively. The areas Sant Singh and Lohgahr on the west show an epidemic figure of 2, but in Dulu and other parts of the city on this side the death rate is still low.

By October a most remarkable invasion of the whole city has taken place; Dulu and quarters to the west have become very badly affected showing epidemic figures of 7·3 to 7·5. Katras Kanhayan, Jamal Singh, the inner portions of Ramgurian and most of Killabangian similarly exhibit a mortality of from 6 to 8 times the normal.

The extreme central area, though comparatively less affected, shows figures representing a death rate of from 3 to 4 times the normal.

The condition in November is much the same, but there has been an extension of high mortality into Karam Singh.

In December the mortality has fallen everywhere, though comparatively more in the outer zone than in the centre, so that with a few exceptions the whole city shows uniformly an epidemic figure of 3 or 4. Khazana, Ghumarian and Dulu still show comparatively high rates.

The rapidity with which the invasion at the beginning of October took place is very remarkable and is well shown in the following table which gives the week in which the first sign of serious increase of death rate and that at which the maximum rate was attained:—

	First marked increase.	*Maximum.*
Gurba Singh	2nd week September	2nd week October.
Ghumarian	2nd „ „	1st „ „
Mahan Singh	2nd „ „	

	First marked increase.	*Maximum.*
Khazana	3rd week September	3rd week October.
Jalewalyan	3rd „ „	3rd „ „
Ramgurian (Outer portion.)	3rd „ „	1st „ „
Bagian	4th „ „	2nd „ „
Sher Singh	4th „ „	2nd „ „
Lohgahr	1st „ October	4th „ „
Jamal Singh	1st „ „	1st „ November.
Kanyahan	1st „ „	3rd „ October.
Ramgurian (Inner portion.)	1st „ „	3rd „ „
Bagh Singh	2nd „ „	3rd „ „
Dulu	2nd „ „	3rd „ „
Beli Ram	2nd „ „	3rd „ „
Nimuk Mandi	2nd „ „	3rd „ „
Chittra Katra	2nd „ „	3rd „ „
Sant Singh	2nd „ „	3rd „ „
Mohram	3rd „ „	4th „ „
Killabangian	3rd „ „	1st „ November.
Chauk Pasian	3rd „ „	2nd „ „

The salient features shown by this study of the mortality are :—

(1) The appearance of an outer ring of increased mortality in August, the extension of this in September to all parts of the city except the central zone and the almost simultaneous appearance in October of intense epidemic conditions in every part of the city except certain areas in the extreme centre.

(2) The prevalence of special intense epidemic conditions in certain parts, notably Khazana, Ghumarian and Mahan Singh.

(3) The existence of a central area which was comparatively speaking protected from the effects of the epidemic.

The distribution of enlarged Spleen and Parasites immediately following the Epidemic of 1908.

In February 1909 I commenced at once a spleen survey of the city. Observations taken at 142 places in the city enabled the distribution to be mapped out fairly accurately.

The accompanying map of Amritsar shows isosplenic lines drawn in accordance with these observations. When particular interest attached to any set of observations all the children that could be obtained were examined and the ground gone over several times. This has enabled one to place considerable reliance on the course of the isosplenic lines ; but unfortunately in one or two instances in the very place where reliable rates would have been interesting the number of children that

could be obtained was very small. The results were recorded under the system described in Chapter III.

The map shows in the first place that around Amritsar there is a broad zone within which the spleen rate is never below about 75%.

Commencing at the north-east corner of the city we find this zone including the greater part of Division 1, all the outer portion of Division 2 and the whole of Division 3. Passing down the eastern side of the city it included most of Division 5 and practically the whole of Divisions 7 and 9. Along the western border of the city it becomes narrowed down and disappears opposite Lohgahr and the crowded Division 11. About half of the total area of the city is thus included in this zone.

Within the 75% zone lies another zone in which the spleen rate is lower. Taking a limit of 75 to 50 % this zone extends inwards on the north as far as the northern limit of Division 11. In a broad band it follows roughly the outer edge of the central area until it reaches its eastern border. Here it narrows very remarkably, there being in this neighbourhood an extraordinarily abrupt transition from the high spleen rate of the outer zone to a very low spleen rate. (*Vide* Map III.)

Following the zone southwards it broadens again and sweeps round the south-eastern corner of the central area passing through Killabangian, broadens out over Chitta Katra and Dulu, is evident in Divisions 11 and 12 and so completes the circuit of the town.

Inside this zone which practically girdles the central area the spleen rate very rapidly becomes reduced and though one can make out imperfectly a zone of spleen rates between 50 and 20% this is narrow and difficult to follow. It is broadest however where the zone 50 to 75% is broadest and narrow where this zone is narrow.

The portion of town within the 20% spleen rate line roughly includes only the extreme centre of the city and does not measure more than a quarter of a mile across. In portions of this the spleen rate has been 0, in others as high as 17%.

All the zones mentioned follow fairly closely the same trend, that is they all widen or narrow at the same point, but there are exceptions which will be referred to.

Along the north of the town the bands are broad and uninterrupted and follow almost exactly the boundaries of the central area. But at the north-east corner there is a disturbance in the line caused by a block of comparatively high buildings projecting outwards. This encroaches on the 75% zone, but does not affect the 75 to 50% zone.

Having passed round this obstruction and another group of high buildings there is a distinct bay formed in which the spleen intensity penetrates more deeply than usual.

The conditions at this point will be referred to later. *Vide* conditions at "Allowalian."

After passing in a convex curve immediately behind the Golden Temple and its surrounding buildings and gardens the zones again pass inwards to form a deep bay, corresponding to an extension of low houses into the central zone. The extension however of high spleen rates and mortality during the epidemic was greater than this would seem to account for. (*Vide* conditions at K. Jamuan.)

Again passing round the south end of the central area in a broadly convex manner, the zones bend northwards to cover a broad tract of the city which extends from the south-west corner inwards for a distance of over half a mile. An interesting feature at this point is the occurrence of an outstanding island with spleen contours of its own corresponding to the group of high houses about Kucha Khai which had already been alluded to.

At this point also there is another deep bay extending into the cowkeeper area of Killabangian in which, though situated deeply within the city, the spleen rate was about 100 %.

The conditions in the zones as regards spleen rate differ not only in regard to the total percentage of enlarged spleen but also as to the degree of enlargement (*vide* Chapter XIV).

The rates for the different zones given in extension[1] are as follows :—

100—75 zone.	Khazana	7	15	43	24	9	91%	163
	Mahan Singh	1	14	41	33	10	90%	70
	Division 7. (Gurba Singh and Ghumerian)	2	12	45	25	16	84%	158
	Chittra Katra		12	42	31	15	85%	55
	Cowkeeper Killabangian		10	43	31	13	87%	83
	Jalewalyan and Ramgurian	1	8	43	26	21	79%	131
	Island (K. Khai)		4	25	12	58	42%	48
	TOTAL ZONE 100—75 excluding K. Khai	3	12	44	27	14	86%	660
75—50 zone.	Sant Singh		4	42	27	27	73%	52
	Allowalian	1	10	21	31	37	63%	74
	Killabangian		6	37	16	40	60%	67
	Churt Singh			25	26	48	52%	75
	TOTAL ZONE 75—50	4	4	30	25	38	62%	268

[1] The figures with percentage symbol are the total spleen rate. *Vide* page 15, Chapter III.

50—20 zone.	Division 12		7	41	51	49%	41
	Tunda Talab	2	13	17	67	33%	46
	Chauk Pasian		2	21	76	24%	80
	TOTAL ZONE 50—20	6	6	25	67	33%	167
Central zone		4	9	86	14%		112

From these figures it will be seen that not only do the different zones differ from one another in regard to the percentage of enlarged spleens among the children but that there are in the outer zone areas of special intensity shown by a greater average size of the spleen, the most noticeable of such areas being Khazana.

It will be clear that there is a very close connection between the distribution of enlarged spleen and the epidemic mortality.

A line representing the inner margin of the 50—75% spleen zone would mark off almost exactly the extension of very high mortality into the city; whilst the parts of the city showing under 30% spleens would represent those parts that were comparatively little affected by mortality.

Spleen rate among Adults.

The distribution of the spleen rate in adults followed the same course as did that among children, as will be seen from the following data :—

	Spleen to umbilicus.	Other classes of spleen.	Not palpable.	Percentage enlarged.	Number examined.
Peripheral zone	13	33	54	46	344
Intermediate zone	2	25	73	27	301
Central area	2	12	87	13	42

Where the children showed about 100%, adults usually showed about 50% enlarged spleen. With lower rates the percentages dropped more in proportion among adults than among children. On the extreme periphery of the city a large proportion of adults showed very large spleens reaching to the unbilicus or beyond.

Parasite rate.

The relation of the parasite rate to the spleen rate in Amritsar has already been given in Chapter III. Further details ascertained by quantitative observations (the numbers of parasites in a 100 fields being noted) are recorded in the table below. In this method the expression negative is only a comparative term meaning that no parasites were found in 100 fields. A great advantage of the method is

that observational error tends to lessen as the columns pass from right to left whilst observations of different observers are comparable. (*Vide* Chapter XIV.)

	Infects over 100 per 100 fields.	Infects over 20 per 100 fields.	Infects over 5 per 100 fields.	Infects under 5 per 100 fields.	Negative.	Percentage infected.	Spleen rate.
Khazana	1	9	6	10	10	76%	93
Mahan Singh	..	1	9	5	8	66%	90
Jamal Singh, 75—50 zone . . .	1	3	4	4	6	65%	66
Hati Gate, 75—50 zone . . .	1	3	6	1	11	50%	47
Kanyan, 75—50 zone	..	2	2	1	5	50%	54
Tunda Talab, 50—20 zone . . .	..	..	1	2	4	43%	37
Chauk Pasian, 50—20 zone . . .	..	1	6	1	15	34%	37
Chowrasta Atara, central zone . .	..	1	..	4	14	26%	13

Considered in regard to the species of parasite found the results were as follows :—

	Simple tertian.	Malignant tertian rings.	Crescents.	Quartan.
Khazana	24	2	4	2
Mahan Singh	11	1	3	4
Jamal Singh	11	0	2	0
Hati Gate	11	0	0	0
Kanyan	5	0	1	0
Tunda Talab	3	0	0	0
Chauk Pasian	8	0	2	1
Chowrasta Atara	5	0	1	0
TOTAL .	78	3	13	7

Breeding places of Anopheles at Amritsar.

Breeding places outside the city.—The accompanying map (Map III) shows the places in which anopheles have been found breeding within and around Amritsar.

To the north-east are large weedy tanks in which *N. fuliginosus* breeds in immense numbers during the months of March and April. Similar sheets occur on the west of the city, and one such source of *N. fuliginosus* is situated to the south-east near Gurba Singh. The sheet of water to the south and west of the city and many of those on the north and west are unsuitable for breeding and no larvæ are found in them. *M. culicifacies* is found breeding in the subsoil water drain and in a drain to the south of Khazana, but I have never found this species very numerous at Amritsar. *N. stephensi* breeds especially in April and May in pools around the city especially to the eastern side. During the rains the temporary breeding places are exceedingly numerous as will be evident from the number marked on the map south of Khazana, the only area in which these have been shown.

Breeding places on the outskirts of the city.—Within or close to the city boundary permanent breeding places are much less numerous than one might suppose. Pools acting as breeding places and lasting some time were found upon waste ground and in gardens in Jalewalyan and on a piece of waste ground near Khazana. *N. fuliginosus* also occurs freely in some small tanks in Jalewalyan. This species was also found breeding in the Municipal gardens and in a drain on the eastern border of the city. Speaking generally breeding within the city boundary only assumes importance during and after the rains.

The most important of such breeding places are :—

(1) Flooded fields.
(2) Shallow roadside pools, pools in compounds, etc.
(3) Small pools formed within the area of houses where building operations are in progress or where a house has fallen down, etc.; these are all of a very temporary nature.

Breeding places within the city.—In the dry weather it would not be too much to say that breeding places do not exist within the city proper. Unlike Delhi I have not succeeded in finding any wells except one or two upon the extreme outskirts harbouring the larvæ of *N. stephensi*.

The large tanks of which there are several in the city have been examined several times with no result, and it is interesting to find the healthiest portions of Amritsar in regard to malaria are to be found in their immediate neighbourhood.

During the rains breeding places are formed in considerable numbers in the outer portions of the city; but they decrease in numbers rapidly as one passes citywards. (*Vide* Map III.)

Distribution of Adult Anopheles.

During 1909, observations were more or less confined to Khazana and Mahan Singh.

In March an examination of the area showed a few *N. fuliginosus* and even less numerous *N. stephensi* on the extreme outskirts only. In May a catch was made of *N. fuliginosus, N. stephensi* and *M. culicifacies* on the outskirts of the area, but up to June adults were restricted to a narrow fringe of houses on the outskirts of the city. At the end of June after several showers of rain adult specimens of *N. fuliginosus, N. stephensi* and *M. culicifacies* were found considerably further in, and as a result of careful search the limit of adults was at this time ascertained to be that shown on the map labelled "end of July." At this time two adult specimens only of *M. rossi* were caught.

Towards the end of August search showed that adults, mainly those of *M. rossi*, were to be caught all over the area in which search had formally been negative, and that the line of adult anopheles was now that labelled "end of August." This line at which adults ceased to be caught even after long search was very carefully followed. In the dense block of buildings north of Khazana it was not above 100 yards from the city wall; but passing southwards it extended up to the borders of the island of high buildings already alluded to as K. Khai and was traced some distance beyond this to the east. Thus in a month the whole of the south-west corner to a distance of a quarter of a mile had become infiltrated by adult anopheles.

At this time such pools as were found on the borders of Khazana swarmed with larvæ, but in the centre of the area many pools, even very suitable ones, dried up without becoming breeding places, showing that the great extension of *M. rossi* noted had taken place with little or no help from pools within the area.

Observations in July upon Mahan Singh showed the presence of adult anopheles throughout the whole area; but with the exception of one or two small pools in a large compound on the boundary no breeding places were found.

In March and April 1910, and later in June, observations were made with a view to ascertaining the distribution of adults of the species *N. fuliginosus* which is found at this time in very large numbers breeding in the weedy tanks outside the city to the north and west. Though at the time intra-mural breeding places were confined to a very few spots chiefly in Jalewalyan, adult *N. fuliginosus* were caught everywhere within the outer zone of the city.

At Mahan Singh they were found as far as the town hall, or in other words to the margin of the central area in this part. In the northern portion of Jalewalyan they were found up to K. Drail on the edge of the central area, and in the southern portion of the same area as far as the buildings at the back of the Golden Temple.

In all these areas it was just possible that breeding places existed though careful search had failed to reveal any of sufficient importance to account for the numbers of adults. But in Ghumarian the conditions were peculiar and quite

preclude any chance of these insects (here as elsewhere found as far in as the border of the central zone) having been produced locally. Ghumarian is an area closely covered with houses. The only open spaces are the market square, a factory, a garden used as a weavers' compound and some small yards in which buffaloes are kept. Systematic search through the whole area failed to bring to light any source of anopheles.

Immediately outside the city at this part however there is a very extensive sheet of water in which, as it was overgrown with weeds, *N. fuliginosus* and *C. pulcherrima* were breeding in large numbers.

By searching the houses, sheds, etc., on the outskirts numerous anopheles, mainly *N. fuliginosus* but also other species, were caught. A sample batch gave as regards *N. fuliginosus*—

N. fuliginosus	Males	8
	Females	32

After passing inwards from the city margin for a distance of about 150 yards, a line was encountered such as had been noted at Khazana in which adults ceased to be caught in shops, houses, etc. But it was found that past this line adults were still to be caught in a stable or cowhouse or to a less extent over wells that were covered with a roof. By searching in situations of this kind anopheles were found to extend to a distance of half a mile into the city. They ceased to be found almost exactly at the line already marked out by the spleen rate.[1]

Passing beyond the region of cowsheds search was negative, but after passing through a portion of the central area anopheles were again found, but in smaller numbers, in cattle sheds of Katra Killabangian.

In all such places males were noticeably absent, only one male being caught "beyond bounds," so to speak, in the whole period of observation. A representative catch made in a single cowshed gave—

N. fuliginosus	Males	0
	Females	53

Further proof that these adults were not produced locally in obscure breeding places which had evaded observation, is to be found in the fact that the insects were of large size showing that they had bred under suitable conditions, which could not be the case had they come from wells, pots, etc., even *N. stephensi* in such a case occurring as very small specimens.

The condition of the ovaries is also peculiar, the ovarian index being of the second type, *vide* page 88, or that characteristic of communities of anopheles

[1] It is perhaps desirable to state that though wells harboured adult *fuliginosus* no larvæ could ever be found in such situations.

remote from breeding places or existing after these have disappeared. As these conditions lasted unaltered over a month there could be no question of any abnormal or merely temporary condition, it being evident that anopheles found their way somehow in large numbers into the city.

Taking the observations as a whole the distribution of adult anopheles (*N. fuliginosus*) followed with remarkable fidelity the 75 per cent. isosplenic line.

Areas in which the Conditions were peculiar.

Kucha Ramanand.—Allusion has been made to a place in the north-east corner of the city where the zone of high spleen rate passes inwards in the form of a bay. In a similar case in the south-east there is an extension inwards of low buildings which satisfactorily accounts for this feature; but in the present case the extension of the high spleen rate inwards has taken place in spite of the fact that the buildings here are quite high.

A study of returns showed that this condition was also associated with a high mortality during the epidemic. Carefully going over the ground I found that, completely hidden away in the centre of blocks of buildings, there were two small areas of waste ground. Whether these were the cause or not of the conditions, it is impossible to say with certainty. A very much larger area of waste ground lying in Division 6, in which anopheles were actually found breeding freely during the rains of 1909, showed no such effect. Kucha Drail, immediately adjoining Kucha Ramanand but exposed to the outer zone, suffered an even heavier mortality, and it seems possible, from the conformation of the city here, that at this point there occurred a veritable anopheles "drive," directing anopheles on to this point.

Kucha Muja Singh.—In the midst of an area with low mortality was an alley very notable for the number of deaths which occurred during the epidemic. This gully was situated in an area for which the spleen rate was found at several places to be 0. Visiting it the spleen rate was found to be 50 per cent. No explanation of this can be offered and time did not allow of further investigation of the conditions.

Kucha Jamuan.—A somewhat similar condition was found in the south of the city in a gully lying in among high houses but in the neighbourhood of the "bay" referred to. This gully was brought to notice on account of the number of deaths, and on visiting it the spleen rate was found to be 30 per cent. Examination showed no apparent reason for this gully being attacked; but the conditions, on account of want of time, could not be fully investigated.

Katra Kanhayan.—This quarter lies well within the city and during the rains of 1909 showed no breeding places. It suffered, however, severely in the epidemic, and in February the percentage of children having parasites in their

blood was very high. As was frequently observed in centrally situated areas invaded by the epidemic this rate exceeded the spleen rate.

Division 11.—This Division occupies roughly an area of $\frac{1}{16}$ of a square mile, or about 40 acres. It is exposed to infiltration of anopheles only on the one side, namely, that facing the open ground on which lies Fort Govindgahr. It carries a population of 16,748 living in rather large well built brick houses, which are so densely packed that the narrow tortuous streets passing through them will scarcely admit of a vehicle being driven through them. Like Division 10 which resembles it in character it exhibited little change in September but succumbed eventually to epidemic malaria, showing a death rate of 342 per mille in October and 250 per mille in November.

Loghahr, Moti Ram and Bag Singh, which lie to the outside of this Division, showed in October epidemic figures of 7·5, 7·8 and 7·3, respectively. Chowrasta Atara and Chauk Pasian lie further in and showed epidemic figures in October of 4·7 and 3·7, respectively.

In the conditions at Amritsar one is irresistibly reminded of the older theories of malaria. The effect is exactly as though a sea of " miasm " had rolled in upon the city swamping all the lower portions of the town and penetrating after a time even among the high buildings of the central zone. The island of K. Khai, almost but not quite submerged as it were in the flood, is a very striking example of this effect.

(ii) Delhi.

Delhi has a population of 206,534 and is the largest city in the Punjab. It is situated on the banks of the Jumna, but separated from the actual river in most parts by a low marshy piece of riverain land known as the Bela. (*Vide* Map 7.) Like Amritsar, Delhi is a walled city though the walls include areas of open land surrounding the Fort and Cantonment. The actual city which occupies about half the space within the walls is very compact.

Mortality.

The intra-mural portion of Delhi is divided into 11 wards, and these being arranged very suitably for our purpose, and separate records kept, the elaborate methods which it was necessary to use for the study of mortality in Amritsar have not been necessary.

Ward I, for the most part composed of bungalows and office, lies facing north and in part directly overlooks the bed of the Jumna. The rest of the city is almost cut off from this aspect by the broad belt of railway which passes through the north end of Delhi.

Ward II, immediately south of the railway, is largely occupied by public gardens. The remaining wards are composed of dense native city. Along the eastern margin are Wards IV, V, XI and X. Wards IV and V are very densely crowded city. Ward XI corresponds in character rather more to the outlying zone in Amritsar.

In the centre of the city are Wards VI and IX.

Along the eastern margin passing from north to south are the Wards III, VII and VIII.

The mortality of the different wards during the epidemic in rates per mille per annum and the periods at which invasion took place are given in the accompanying table :—

		September.	October.	November.	December.	Highest weekly rate.	
Facing Jumna . .	Ward I .	178	262	125	104	305	1st week September.
Public Gardens . .	Ward II	93	147	117	88	155	3rd „ „
Eastern border of city .	Ward IV	108	236	175	165	245	4th „ „
	Ward V	106	193	151	78	210	4th „ „
	Ward X	..	..	..	..	255	3rd „ „
	Ward XI	..	..	..	..	245	2nd „ „
Central . . .	Ward VI	78	122	88	46	160	4th „ „
	Ward IX	84	163	111	..	200	4th „ „
Western border . .	Ward III	99	151	91	57	170	2nd „ „
	Ward VII	72	115	89	70	120	4th „ „
	Ward VIII	84	162	111	79	175	4th „ „

It will be seen that the ward most seriously affected was Ward I. In the case of this ward, which as we have said overlooks the bed of the Jumna, mortality rose above a hundred per mille in the 1st week in September, a date antecedent to that of the onset in any other part of the city.

The next most seriously affected wards were Wards IV, V, XI and X which lie along the eastern border. In Ward XI which is most exposed to infiltration and nearest the bed of the Jumna the mortality first rose above 100 per mille in the 2nd week of September. In Ward X, which adjoins Ward XI on the inner side, the invasion occurred in the 3rd week in September. In Wards IV and V the first marked increase in mortality occurred only on the 4th week of September. Ward II, which contains extensive gardens with many opportunities for the formation of breeding places, was not very severely affected and the epidemic was rather late in making its appearance felt (3rd week, September).

The mortality in the western border of the city was if anything less than that in the central wards. The least affected ward was Ward VII.

In spite of the first invasion occurring at slightly different times in the different wards the epidemic reached its greatest development almost simultaneously throughout the city.

Behaviour of Delhi to Former Epidemics.

In 1906 the mortality in the different wards was as follows, the figures being approximate only as they have been compiled from a curve :—

	August.	September.	October.	November.	December.
Ward I	49	168	222	146	111
Ward IV	71	134	172	184	91
Ward XI	77	154	229	164	74
Ward X	91	84	160	161	80
Ward V	63	72	85	76	55
Ward VI	48	71	96	95	64
Ward VII	65	75	96	121	64
Ward VIII	59	74	94	111	68

It will be seen that as in 1908 the most affected ward was Ward I. The next most affected was Ward XI; Wards IV and X also showed a marked epidemic mortality.

In Wards VI, VII and VIII the mortality curve showed the merest indication of an epidemic rise.

In 1903 the mortality was as follows:—

	August.	September.	October.	November.	December.
Ward I	28	57	87	127	105
Ward XI	41	70	117	78	70
Ward V	44	49	75	71	58
Ward VI	49	62	71	65	65
Ward VII	41	56	64	53	50

The affected wards have therefore reacted very consistently to epidemic conditions.

Distribution of Enlarged Spleen.

Delhi was visited in April 1909. The conditions in regard to spleen rate were then as follows :—[1]

Ward XI	4	17	62	7	10	90%	57
Ward X	..	15	25	30	30	60%	45
Wards IV and V	..	14	41	17	26	74%	67
Ward VI	..	..	35	25	40	60%	40
Ward VII	..	..	28	20	52	48%	50
Ward IX	..	4	15	21	60	40%	75

The spleen rate therefore gave almost an exact indication of the degree to which the different wards were affected by mortality.

In Ward XI two observations gave 86 per cent. and 70 per cent. on the outskirts and central portions, respectively. In a low quarter near the Jumma Musjid spleen rate at two places was 100 per cent.; immediately to the west of this area in Ward IX, in rather dense city, the rate was much lower, being only 20 per cent. Further on in a different class of house it was again high, being nearly 50 per cent. In Ward IV observations at two places showed 100 per cent. and in Ward V high rates were also obtained.

In Ward VI, in an area of very densely packed houses, the spleen rate was low (17 per cent.); it was high (89 per cent.) in a part close by where there were stables, woodsheds, etc. In Ward VII it was very high in the neighbourhood of one of the gates, but low in six other areas tested.

Breeding Places of Anopheles.

In pools in the bed of the Jumna and in swampy parts of the Bela anopheles were found breeding in large numbers. They were specially numerous in small

[1] The sixth column gives total percentages. *Vide* Chapter III.

pools made in the sand by the side of the river, in pools left by the river, and in a creek. Such breeding places however were a mile or more from the city proper (*vide* Map 7).

A comparatively small number of larvæ were found in a ravine near the south-east corner of the city; but over the wide area surrounding the city away from the river it was extremely difficult on two occasions to find any breeding places at all. To the north of the city breeding places occurred in drains, and other situations.

Within the city there is a canal passing through the northern portion and pools are not infrequently found in connection with irrigation of the gardens. Standing water was also seen in connection with a horse trough and in a few other situations. On the whole there were within the walls exceedingly few breeding places of the ordinary kind (*vide* however "wells"), certainly nothing to account for the malaria of the whole city.

In Ward XI a number of large disused wells were found to be swarming with larvæ of *N. stephensi*, but in the ordinary small wells of the city I did not succeed in finding larvæ. There are one or two large compounds but no breeding places in them at the time of my visits. In Ward IV no local breeding places of an ordinary description were found. Want of time and the character of the houses prevented any thorough examination of wells, but those examined were negative.

Distribution of Adult Anopheles.

Examination of houses, sheds, etc., in Ward XI yielded a small number of anopheles including *M. culicifacies*, *N. stephensi* and *N. fuliginosus*. In the centre of Ward IV anopheles were found fairly abundantly and catches have on several occasions been made in this situation. Had the condition of malaria been due entirely or mainly to wells we should have expected to find only *N. stephensi*. An actual catch however of which a record has been kept was—

N. fuliginosus	6
M. culicifacies	12
N. stephensi	3
P. rossi	4

Enough has been said to show that as in Amritsar there is a close connection between the mortality, the spleen rate and anopheles distribution. But it must be evident that the malaria of Delhi is a complicated question requiring more time than I have had at my disposal to investigate adequately.

The brief sketch given will, however, help us later on in arriving at a knowledge of the nature of the epidemic we are considering. That the same wards were affected in a proportionate degree in other epidemic years and that the

distribution of the spleen rate corresponds to that of the epidemic conditions is noteworthy.

(iii) Palwal.

So far we have considered two of the cities of the Punjab. The towns that follow are such as may be called small towns of the Punjab. The conditions in regard to them are important since collectively their population numbered in 1901 over a million and it was among them that the worst effects of the epidemic were recorded.

At Palwal the recorded mortality in October reached 420 per mille, this rate being exceeded only by that at Bhera and Hodal. This town was therefore visited as soon after the epidemic as possible (April).

The town had a population in 1901 of 12,830. It is situated in the Gurgaon District, south of Delhi, in a tract which suffered severely during the epidemic, and the physical features of which will be discussed in the chapter on rural malaria.

The town itself is built upon a high mound which is entirely artificial, being the result of centuries of accumulation. The country around the town, however, is flat and possesses no natural drainage, the nearest nullah being several miles from the city. Moreover this flat land is excavated in all directions and the soil is very impervious. After rain its suitability for the breeding of anopheles could scarcely be excelled.

The condition of water-logging at the time of my visit was very pronounced, the subsoil water at places being within two or three feet of the surface. Large excavations were also full of water and naturally suggested themselves as causes of the malarial epidemic, though it is doubtful from their nature if they could have played any considerable part in this respect. During the rains of 1908 the surrounding low land was so flooded that the town could only be approached through water, whilst donkey and cattle owners were much distressed for want of fodder.

Like most Punjab towns Palwal is extremely compact. The streets are paved throughout and descend steeply to the various gates. By reason of the slope of the mound, drainage within the city is excellent, and it might seem at first sight very curious that it should have been affected, as it was in 1908, by malaria.

The central part of the town, composed for the most part of brick buildings, is situated on the summit of the mound. It is sparsely populated, many of the large houses being unoccupied; and some areas are apparently almost if not quite deserted. Around this central part, especially to the north and west, are qualid suburbs, if we may dignify them by this name, partly situated on the slope

of the mound and partly on the flat ground. Unlike the central area these suburbs, mostly formed of mud-built huts occupied by Chamars and other low castes, are densely populated.

The greater part of the population of Palwal therefore live in a zone not above 300 yards wide lying round the foot of and on the slope of the conspicuous but partially deserted central mound.

Mortality.

The curve of mortality at Palwal is shown in Chart 3. It is noticeable as rising even higher in November than in October, the same notched summit being seen as occurred in the curve of Amritsar. The great majority of deaths were recorded in the crowded quarters already referred to, but information was too scanty to enable a detailed survey to be made.

According to age the deaths were as follows :—

Stillborn	33
Children under five years	590
Other ages	468

Reaction to Epidemic Conditions.

Like Amritsar, Palwal had already suffered several times from severe epidemics of malaria. The most serious of such visitations occurred in 1878. There was also a very high death rate in the following year when the district was affected by the great 1879 epidemic.

Spleen Rate and Parasite Rate.

Taken collectively the spleen rate among children examined gave the following percentages :—

4	15	49	19	12	88%	147

Taking only the outskirts, the rate was higher and the increase in the size of the organ very marked. The rate for the quarter Chamarwara was as follows :—

13	20	50	13	3	97%	30

Among adults the spleen rate was :—

7	13	7	19	54	46%	55

In a small area in the extreme centre there seemed a slight reduction in the spleen rate, but it was difficult to get sufficient children in this almost deserted portion to get reliable results. The examination of 16 children gave—

0	19	31	12	38	62%	16

Palwal was therefore affected throughout by malaria of high intensity. If a central protected zone existed it was small and contained but few people. Malaria in the peripheral portions of the town was in places extremely intense.

An examination of the blood of children for parasites gave—

Infections over 100.	Infections over 20.	Infections over 5.	Infection under 5.	Negative.	Percentage infected.	Number examined.
1	7	14	8	6	83	36

The species found being as follows:—

Simple tertian.	Malignant tertian.	Crescents.	Quartan.
24	4	4	0

Breeding Places of Anopheles.

In 1908, when Palwal was surrounded by standing water, there must have existed around it a continuous ring of breeding places, and as the water subsided many acres of land covered with shallow pools, eminently suited to the breeding of anopheles (*vide* Amritsar), must have been formed.

A good idea of the conditions during the rains was obtained as the result of a fall of several inches at the time of my visit, though at this time the season was too early to expect to find larvæ in open pools. At the north end of the town cultivated fields, then covered with an almost continuous sheet of water, extended up to and even among the houses. On the west were acres of waste land covered with innumerable pools and collections of water lying upon the impervious soil. On the east were large sheets of permanent water and low water-logged fields.

Within the town breeding places were much less numerous and in the central area on the mound no pools were found to retain water for more than a very brief period.

At the time of my visit anopheles were not numerous, but a number of *M. culicifacies* were caught in different parts of the town. The size of Palwal was apparently insufficient to offer any obstacle to the spread of the epidemic. Like Amritsar it appeared to have been chiefly influenced from its surroundings.

(iv) Bhera.

Bhera is a town of 18,680 inhabitants situated on low lying land near the Jhelum river in a tract which suffered very severely in the epidemic. (*Vide* Map 10.) It was visited in July 1909. Like Palwal it was surrounded by floods in 1908, so that it is stated a boat could have gone round the city. At the time of my visit there was much water lying about the town and the subsoil water was very close to the surface, in some parts less than six feet.

The town is more straggling than Palwal and there are large areas of waste land within its boundaries.

The curve of mortality is given in Chart III. The first distinct rise in the number of deaths occurred in the last week of September, the onset of the epidemic at Bhera being therefore almost exactly synchronous with its appearance at Amritsar.

The mortality was remarkable for the enormous proportion of infants, the number of deaths at different ages being—

Stillborn	22	Over 5 and under 10 years	51
		„ 10 „ 20 „	24
Under 1 year	260	„ 20 „ 30 „	18
„ 2 years	130	„ 30 „ 40 „	14
„ 3 „	61	„ 40 „ 50 „	9
„ 4 „	40	„ 50 „ 60 „	24
„ 5 „	12	Over 60	94
Children under five years	503	Other ages	234

Past History.

Bhera is interesting from the fact that the town suffered severely from epidemic malaria in 1903, not because of excessive rain but following, it is stated, upon *the flooding of the surroundings by the Jhelum river.* It has suffered in some other epidemic years but never apparently so severely as in 1908.

Spleen rate and Parasite rate.

The spleen rate was taken in eleven places, being collectively—

9	13	47	23	16	84%	113

The centrally situated portions were examined to ascertain what amount of reduction in the spleen rate, if any, occurred in among dense blocks of houses; but as 21 children gave a spleen rate as follows any definite reduction is doubtful:—

0	4	52	19	24	76%	21

In adults the rate was 36 per cent.

In any case such an area would have had but a theoretical interest as the protection must have been very slight and the area so small as to make it difficult to get more than the number of children quoted.

The parasite rate in July was as follows:—

Infection over 100.	Infection over 20.	Infections over 5.	Infections under 5.	Negative.	Percentage infected.	Number examined.
0	0	6	8	26	37%	40

The parasites were, in the slides examined, without exception the simple tertian species.

Breeding Places of Anopheles.

Anopheles were breeding freely in weedy pools just outside the city and in one or two small puddles within the city boundary. It is impossible to say what the conditions as regards breeding places during the rains might have been.

(v) Miani.

Miani is a town of only 7,220 inhabitants, situated near Bhera, but so situated that a portion of the town lies on slightly higher ground which forms the bank of the riverain at this spot.

Though the southern part of the town was on comparatively dry ground the northern portion lay on water-logged ground with much standing water about and the subsoil water level of from 5 to 6 feet from the surface.

The mortality rose in the last week of September and reached a figure of 403 per mille in the second week in October. The spleen rate was—

5	19	35	20	21	79%	56

No part of the town was found unaffected.

(vi) Gujrat.

Gujrat, with a population of 19,048, is built on a very high mound surrounded by low flat cultivated land. Unlike Palwal the portion on the summit of the mound is thickly populated.

The mortality first reached 160 per mille on the last week in September and attained to a rate of 247 per mille on the second week of October, but this high rate was maintained for a short time only.

The spleen rate on the margins of the city was—

0	5	24	21	49	51 %	37

In the central portions it was even lower—

·7	·7	15	21	62	38 %	130

CHAPTER VII.

Conditions in Rural Areas.

I.—Villages of the Amritsar and Gherinda Thanas.

Though the figures are high the returns for the district of Amritsar do not indicate such high mortality as occurred in the city. For the district as a whole the increase in mortality above normal was about five times the non-epidemic average.

Taking the figures for the separate thanas the mortality is seen not to have been uniform.

	Normal rate.	Deaths, October 1908.	Epidemic figure.
West.			
Amritsar	165	1,613	9·7
Gherinda	173	1,341	7·7
North.			
Jandiala	194	947	4·8
Wazir Buttal	159	515	3·6
Kuthna Nangal	215	1,152	5·3
East.			
Ajnala	207	1,150	5·5
Lopoki	156	761	4·8
Randas	109	452	4·0
South.			
Tarn Taran	233	1,348	5·7
Sirhali	192	744	3·8
Vairowal	122	452	3·5

The two most seriously affected thanas lie around and to the south-west of the city of Amritsar.

The result of mapping the two thanas of Amritsar and Gherinda according to the epidemic figures of individual villages is shown in Map 8. It will be seen

that roughly speaking, though[there are areas which by this method appear to have been less affected than others, the distribution of high mortality is very general. Too implicit reliance on the figures may lead us astray, but there seem to be islands of comparatively unaffected villages and areas of specially intense activity.

Conditions found at Villages visited.

Atari.—Atari is a large village with a recorded population of 3,216. It forms a compact block of buildings, the centre being occupied by large more or less ruinous palaces.

In October 1908 only 35 deaths are recorded, so that the mortality does not seem to have been very high (130 per mille), thus corresponding with its low epidemic figure of 5.

In March 1909 the spleen and parasite rates were as follows :—

Spleen rate.

5	14	44	17	19	81%	41

Parasite rate.

Infections over 100.	Infections over 20.	Infections over 5.	Infections under 5.	Negative.	Percentage infected.	Number examined.
0	2	7	3	22	35%	34

The parasites found being—

Simple tertian	11
Crescents	1

Though many excavations lay around this village, it does not seem to have suffered very severely in the epidemic.

Dande.—Dande is a small village having a recorded population of 505.

The recorded deaths in October 1908 were 9, about 200 per mille. The spleen rate in March 1909 was—

0	4	45	32	19	81%	22

Rangahr and Raniki.—These villages lie close together. They have a recorded population of 783 and 781, respectively. The deaths recorded in October 1908 were in both cases 13 (rates of about 200 per mille). The spleen rate in March 1909 was—

12	12	38	31	6	94%	16
0	25	42	25	8	92%	12

Kahangahr.—This was a large village. It was markedly different in character to the others, being surrounded closely on all sides by cultivated land and trees. It also gave the impression of being more prosperous.

The recorded deaths in October 1908 were only 5.

The spleen rate in March 1909 was—

3	3	45	42	6	94%	31

Mahawa and villages in the neighbourhood.—It will be seen from the map that these were all very severely affected. It is to be regretted that none of them were examined. But it is worth mentioning that the country in this direction was seen to be lower than around Atari. Collections of water were very conspicuous features, and at Mahawa there was a jheel. Mahawa showed an epidemic figure of 18 and a calculated mortality of 460 per mille.

Gumtala and villages in the neighbourhood.—In the Amritsar thana it will be noticed that judging from the recorded mortality there is a comparatively unaffected tract to the north-west corner, surrounding one village with a higher rate. This arrangement of mortality corresponds very closely with the physical features. Gumtala lies in a gentle depression of the kind we have several times referred to. Close to it is a drained jheel, and the main drain of this part of the country passes through this area. The subsoil water in April 1910 was 5 feet from the surface. The mortality during October 1908 was 241 per mille (epidemic figure 12).

The villages Kambo, Kairabad, etc., are situated on a distinct though scarcely visible rise in the land, and the depth of the subsoil water in Kairabad in April was 10 feet.

We can therefore trace a distinct connection between the intensity of epidemic conditions and the low lying situation of the village. Yet this difference in situation is one at the most of a few feet.

II.—Villages around Palwal.

The tract in which Palwal and Hodal are situated and which continued to the south includes Muttra and Agra Districts (which it will be remembered were the worst affected of any districts in the United Provinces) lies between the Jumna river and the high land of Alwar.

It is a level alluvial plain with but few facilities for drainage and liable to floods.

Ferozepore Jhir and Nuh are situated very curiously in a shut in valley more

Kahangahr.—This was a large village. It was markedly different in character to the others, being surrounded closely on all sides by cultivated land and trees. It also gave the impression of being more prosperous.

The recorded deaths in October 1908 were only 5.

The spleen rate in March 1909 was—

3	3	45	42	6	94%	31

Mahawa and villages in the neighbourhood.—It will be seen from the map that these were all very severely affected. It is to be regretted that none of them were examined. But it is worth mentioning that the country in this direction was seen to be lower than around Atari. Collections of water were very conspicuous features, and at Mahawa there was a jheel. Mahawa showed an epidemic figure of 18 and a calculated mortality of 460 per mille.

Gumtala and villages in the neighbourhood.—In the Amritsar thana it will be noticed that judging from the recorded mortality there is a comparatively unaffected tract to the north-west corner, surrounding one village with a higher rate. This arrangement of mortality corresponds very closely with the physical features. Gumtala lies in a gentle depression of the kind we have several times referred to. Close to it is a drained jheel, and the main drain of this part of the country passes through this area. The subsoil water in April 1910 was 5 feet from the surface. The mortality during October 1908 was 241 per mille (epidemic figure 12).

The villages Kambo, Kairabad, etc., are situated on a distinct though scarcely visible rise in the land, and the depth of the subsoil water in Kairabad in April was 10 feet.

We can therefore trace a distinct connection between the intensity of epidemic conditions and the low lying situation of the village. Yet this difference in situation is one at the most of a few feet.

II.—Villages around Palwal.

The tract in which Palwal and Hodal are situated and which continued to the south includes Muttra and Agra Districts (which it will be remembered were the worst affected of any districts in the United Provinces) lies between the Jumna river and the high land of Alwar.

It is a level alluvial plain with but few facilities for drainage and liable to floods.

Ferozepore Jhir and Nuh are situated very curiously in a shut in valley more

than usually apt to be flooded and waterlogged. It will be noticed from figures given that all the thanas suffered very heavily.

		Normal.	Figures October 1908.	Epidemic figure.
Northern tract	Gurgaon	170	1,220	7·1
	Faraknagar	72	781	10·8
	Jatusana	105	837	8·0
Compact high ground	Rewari	148	997	6·7
	Sohna	52	419	8·0
	Faurn	75	687	9·1
Along foot of Alwar hills	Nuh	122	1,404	11·5
	Ferozepore	131	2,346	17·9
Alluvial plain of Jumna	Palwal	142	1,357	9·5
	Hodal	112	1,083	9·6
	Hosiapur	83	681	8·2
	Punahana	127	1,324	10·4
	Hattin	134	1,281	9·5

Reaction of the Tract to Epidemic Conditions.

The normal average of deaths in the Gurgaon district is about 1,500. In the month of October this usually is raised, showing that the district is consistently malarious. But between the years 1880 and 1907, excluding 1904 in which year the figures were raised by deaths from plague, the usual October rate of about 2,000—3,000 deaths has only been three times much exceeded, namely in 1879, 1900 and 1901, deaths numbering in these years 2,967, 4,245 and 3,549, respectively. For a period of about 27 years therefore this tract has suffered very moderately from epidemic malaria, and indeed the highest epidemic figure reached by any thana has been 4 (Palwal and Punahana in 1879 and Nuh in 1901).

But in 1879 the deaths numbered 14,179 as against 15,740 in 1908. Considering the probability of registration being less accurate at this time, it is probable that epidemic conditions in 1879 were as severe or even more severe than they were in

1908. The behaviour of some of the thanas at this time contrasted with their reaction in 1908 shows as follows :—

	Normal.	October 1908.	October 1879.
Gurgaon	170	1,220	1,179
Palwal	142	1,357	1,274
Jatusana	105	837	812
Taori	75	687	594
Punahana	127	1,324	737
Nuh	122	1,404	915
Ferozepore	131	2,346	883
Rewari	148	997	1,877

It is interesting to see that Rewari, the healthiest of the thanas in 1908, is here one of the most severely affected, Nuh and Ferozepore in 1879 being only moderately affected.

Conditions in the Villages examined.

Janoali.—This was a large village about five miles from Palwal. At the time of my visit in April it was still surrounded by water, to avoid which it had to be approached by a devious route. The subsoil water on the margin of the village was between two and three feet from the surface.

The spleen rate was—

7	28	47	17	0	100 %	42

Dhatir.—This village was chosen as being situated on sandy soil. It is a large village (population of 2,200) on a mound, and though visited the day after rain no water had accumulated anywhere within the village. Around the village there were but few excavations, the soil evidently not being suitable for building.

The spleen rate was—

1	10	39	21	27	73%	92

The parasite rate was—

Infection over 100.	Infection over 20.	Infection over 5.	Infection under 5.	Negative.	Percentage infected.	Number examined.
0	2	6	3	25	30%	36

All the parasites found were the simple tertian variety.

Pirthala.—A large village on sandy soil. The spleen rate was 75 per cent.

III.—Villages of the Bhera, Miani and Jaurian Thanas. (*Vide* Map IV.)

The thanas of Bhera, Jaurian, Miani, Pind Dadan Khan, Jalalpur and Lilleh occupy the broad oval valley of the Jhelum above Shahpur. The chief physical features of this riverain and the relation of this tract to the higher lands which surround it will be clear from the map. (Map I.)

Above Miani high land approaches close to the river, and a little higher up near Rasul, hills come close together forcing the river through a narrow gap. Above this the Jhelum has again a wide valley in which lie the thanas of Jhelum, Dura, Sohawa, Domeli and Dummon.

Mortality.

In 1908 the figures for the different thanas in the Jhelum riverain below Rasul were as follows :—

	Normal.	October 1908.	Epidemic figure.
Jalalpur	55	826	9
Pind Dadan Khan	43	791	19
Lilleh	47	593	13
South Bank.			
Miani	60	538	8·9
Bhera	39	707	18·1
Jaurian	89	629	7

It is very interesting to observe that epidemic conditions of like severity occurred in the Jhelum valley *above* the restriction at Rasul, the figures for the thanas in this situation being—

Sohawa	28	185	6·9
Domeli	56	517	8
Dura	64	468	7
Jhelum	85	826	9
Dhumman	69	630	9

Mapped out in detail the Bhera and Miani thanas appear as shown in Map 10. The villages in the Bhera thana are remarkable for the uniform high mortality. They very rarely show an epidemic figure below 10 or a rate per mille during October less than 250. As a rule the rate is from 300—400 per mille, and in some it is even higher. Wazidi, with an epidemic figure of 41, gave a calculated mortality during October of 651, Kohlian with an epidemic figure of 41, a death rate of 439. The map shows clearly that the highest rates are in villages lying close along the river margin. As the edge of the riverain is reached at Hathiwind the rates become reduced (*vide* Map 10). This effect is even more pronounced in the Miani thana.

Reaction of the Tract to Epidemic Conditions.

In 1892 the tract was even more sharply visited than in 1908, the numbers of deaths in the different thanas in October 1892 as compared with those in October 1908 being as follows :—

	Normal.	October 1908.	October 1892.
Jalalpur	55	826	693
Pind Dadan Khan	43	791	369
Lilleh	47	593	823
Miani	60	538	143
Bhera	39	707	295
Jaurian	89	629	423
Sohowa	28	185	286
Domeli	66	517	684
Dura	64	468	606
Jhelum	85	826	1,053
Dhumman	69	630	402

It is interesting to note that Bhera, on this occasion, was not the worst affected thana, the centre of the epidemic being further up the riverain.

Conditions in the Villages visited.

The following villages were visited in August 1909.

Alipur.—Alipur is a large village situated a little further inland than Bhera from the river. It had an epidemic figure in October 1908 of 30 and a recorded

death rate of 377 per mille. There were excavations about the village, but there were no special features to differentiate it from many other villages less severely affected. The subsoil water was 10 feet from the surface (July 1909). The spleen rate was—

2	0	54	38	6	94 %	50

Jamat and Ranga.—Two villages lying one on either side of an inundation canal and within a mile or so of the river. They were surrounded by fields and the usual excavations. There was nothing exceptional in the conditions at this time. The subsoil water was 8 feet from the surface. The two villages combined had in October 1908 an epidemic figure of 20 and a recorded death-rate of 461 per mille. The spleen rate of Jamat was 81 per cent. and of Ranga 87 per cent. The two combined gave—

5	11	45	26	12	88 %	53

Dhal.—Dhal was a large village, with an epidemic figure in October 1908 of 18 and a calculated rate of 332 per mille. It was comparatively speaking on high ground. The subsoil water was 9½ feet from the surface. The spleen rate was—

0	26	48	11	15	85 %	27

Kohlian.—Kohlian in October 1908 had an epidemic figure of 41 and a calculated rate of 439 per mille. It lay nearer the river than any other village examined with the exception of Jamat Ranja. The appearance of the ground was as though water might lodge freely and it was largely uncultivated. The subsoil water was 7 feet from the surface. The spleen rate was—

0	8	68	12	12	88 %	25

Hafizabad.—Hafizabad was a large village, a mile or two from the river. It gave in October an epidemic figure of 18 and a calculated rate of 382 per mille. The subsoil water was 8 feet from the surface. The spleen rate was—

5	26	47	16	5	95 %	19

Khan Mahomad Wala.—This was a large but squalid village situated some miles inland. But the subsoil water level was high (5 feet) and in its neighbourhood were large areas inundated by a neglected inundation nullah. The epidemic figure for October 1908 was 17, but the calculated rate was only 161 per mille. The spleen rate was—

0	23	56	26	3	97 %	30

Taken collectively adults in the above villages gave a spleen rate of—

2	7	5	12	74	26 %	41

Hathiwind.—This village was specially chosen for a visit as it lay on the edge of the higher country in the adjoining thana of Bhalwal. Though evidently

under different conditions to the other villages, there was a good deal of water lying in excavations near by. The subsoil water was 12 feet from the surface. The spleen rate was—

0	0	52	21	27	73 %	23

Villages of the Gujrat Thana.

The Gujrat district may be looked upon as partly submontane where it lies below the hills of Naoshera and partly Doab where it lies between the Jhelum and Chenab rivers. The former tract consisting of the thanas of Karian, Karianwala, Jalalpur and Gujrat is crossed by numerous torrents passing from the hills to fall into the Chenab river. The latter comprising the thanas of Lala Musa, Dinga, Kutheila Sheikan, etc., is of a different character, being for the most part higher land and less heavily watered. The thana of Aurungabad lies geographically in the upper portion of the Jhelum valley, separated from Gujrat by some low hills. It is the submontane portion which has suffered so severely from the epidemic and the worst affected of the thanas was that of Gujrat. (*Vide* Map I.)

Of all the thanas that of Gujrat is most cut up by streams falling into the Chenab. At the time of my visit rain had swollen many of these, and it was possible to see how when so swollen they were liable to break their banks and inundate large areas.

Mortality.

Mapped out in epidemic figures for the villages an arrangement very like that seen in the Amritsar district is evident. But in this case the contrast between tracts in which the villages have been severely affected and those less affected is greater. To the north-west will be seen a considerable number of villages with low rates; this portion of the thana adjoins that of Dinga in which the epidemic figure was in October only 5·9. The country here is also of higher character than elsewhere. Forming a sort of continuation of this high land eastwards is an area occupied by a single village Nairowali with a figure of only 2. To the south, and especially in the south-west corner, the villages on the other hand all show without exception very high rates indeed. Groups of villages showing especially high mortality are also seen at "*a*" and "*b*."

Reaction of the Tract to Epidemic Conditions.

Gujrat has been affected by severe epidemic conditions on several occasions. In 1900 the deaths in October were 3,883 or nearly three times the normal rate; in 1892 they numbered 8,351 and in 1890, 15,744 or half as many again as they did in October 1908.

The behaviour of the different thanas in these years was as follows :—

	Deaths in October 1908.	Epidemic figure 1908.	Deaths in October 1892.	Epidemic figure 1892.	Deaths in October 1908.	Epidemic figure 1890.
EASTERN GUJRAT.						
Karian 123	1,008	8	556	5	753	6
Karianwala . . . 161	1,474	9	1,070	6	2,312	14
Jalalpur 102	884	10	1,372	5	4,498	16
Gujrat 180	2,000					
JHELUM VALLEY.						
Aurungabad . . . 103	807	8	685	7	659	6
WESTERN GUJRAT.						
Lala Musa . . . 205	1,575	7	927	4	1,527	7
Dinga 135	800	6	645	5	1,278	9
Parinwala . . . 176	1,066	6	1,365	8	2,413	13
Kutherla Sheikan . . 121	564	4	881	7	658	5
Kadriabad . . . 41	169	4	352	9	215	5

Though the effects in the different thanas vary, it is clear that there is a general tendency for certain of them to be consistently more affected than others. It is interesting to note that Dinga and Parianwala, though comparatively mildly affected in 1908, were nevertheless severely affected in 1890 when epidemic conditions were still more intense over this area than in 1908.

Conditions in the Villages visited.

Nairowali.—This village which as noted above had an epidemic figure of only 2 is situated on a piece of gently swelling ground. The river bed marked on the map to the east was no longer recognisable except as a tract of low partially flooded land. The channel to the west of the village on the contrary was in active flood but ran not in a depression but along high land part of which at a distance of two miles or more formed the gentle rise upon which Nairowali stood. Around the village were a number of excavations and a number of anopheles larvæ were found, but one could see even with the unaided eye that the ground sloped away in most direction from the village and the villagers stated that they were not subject to floods. The spleen rate was—

0	0	8	17	74	26 %	35

Shadiwal.—This was a very large village situated on a nullah subjected to flooding. The epidemic figure in October 1908 was 25. But the spleen rate was low—

0	0	21	21	58	42 %	38

Darawala and Tricha.—The first named village having the extraordinary epidemic figure of 70 and being surrounded by other villages with very high rates an effort was made to visit it. But the flooded condition of the country prevented my getting further than Tricha. Even this village, since it lay across a deep sheet of water, was not actually entered.

Kuthala.—This village lies near the Chenab river and showed an epidemic figure of 27. A nullah in the neighbourhood was stated to flood the village. All round the village the land was low and swampy looking. The subsoil water was 3 feet from the surface. The spleen rate was—

5	10	40	20	25	75 %	40

Gurali and Gurala.—These two villages showed epidemic figures in October 1908 of 46 and 21, respectively. They were situated in broad low-lying plains that gave one the impression of having been the bed of a large river. The land was low-lying to an exceptional degree and the subsoil water was very near the surface. The spleen rate at Gurali was—

3	27	39	21	9	91 %	33

Nurpur near Gujrat.—This is a small village not marked on the map. It lay in the line of one of the nullahs which pass round Gujrat city. The spleen rate was—

0	25	31	6	38	62 %	16

Nurpur.—This village had an epidemic figure of 54. It was found to lie in the course of a nullah which became flooded by the Jehangir river. Another village in the neighbourhood was found to be situated on an old bed of the same river and to be liable to floods when this river received more than a certain amount of water. The spleen rate in both villages was high but has not been recorded. The focus of epidemic conditions at "*b*" seemed to be in relation to floods from the abovementioned river.

Shahdiwal and Mand.—Mand (*c*) lay on comparatively low-lying ground obviously liable to be flooded by the river. Shahdiwal and other villages forming the focus as "*a*" at the time of my visit were surrounded by water which I was informed was the result of flooding by a nullah to the north.

Harianwala.—The epidemic figure for October was 5. The spleen rate was—

0	0	13	26	61	39 %	31

In Gujrat the association between severe epidemic conditions and flooding was peculiarly marked.

CHAPTER VIII.

Conditions in Non-Epidemic Areas and in Epidemic Areas in Non-Epidemic Times.

I.—Villages of the Shahpur Thana. (*Vide* Map 10.)

The conditions in the Jhelum riverain north of the point near Kushab and Shahpur where the river turns abruptly to the south has been referred to.

Followed southwards beyond the thana of Jaurian the riverain is still traceable through the thana of Shahpur and that of Sahiwal.

Shahpur is almost entirely riverain land, but on the border furthest from the river there is an abrupt change to Doab land which in this situation is very abruptly marked off and exhibits characters that are almost those of a desert. To the south of the thana the desert, like conditions approach close to the river and inundation canals which have been a constant feature of the riverain from Bhera downwards cease at this point and give place to canals of the high irrigation system. Nevertheless the riverain is still clearly marked in certain maps throughout Sahiwal.

In accordance with a general law in riverains there is a tendency for the lowest land not actually occupied by the river to be close under the opposite bank. In Shahpur thana this arrangement was shown very clearly, for whilst the river ran to the west of the thana the most water-logged land was that lying close along the desert margin in the neighbourhood of the villages Saidaspur and Wegowal on the eastern margin (*vide* Map 10).

Mortality.

The result of mapping the villages by means of epidemic figures is shown in Map 10. The most noticeable features are the group of villages with very high figures which adjoin the thana of Jaurian to the north and the extremely low figures shown in the villages to the south as Sahiwal is approached. As the thana of Sahiwal as a whole showed an epidemic figure of only 2 it is probable that most of its villages were similarly unaffected. Two other features are also seen, namely, an isolated area of high epidemic conditions due to the villages Wegowal and Sardarpur and a similar area on the banks of the Jhelum due to the single village of Kandan.

Conditions in the Villages visited.

Shahpur.—Shahpur though a town possesses a population of only 5,855 and in reality is little more than a large village. It is situated on flat alluvial land about two miles from the river. At the time of my visit (August) it was in

comparison with places further up the riverain conspicuously free from standing water. The subsoil water was at a depth of 12 feet. In the centre of the city owing to the accumulation of soil on the site the depth was 28 feet. In October 1908 the death rate was only 52 per mille and the highest weekly rate to which it rose was 177 per mille. It was therefore much less affected than any other town we have yet considered. The spleen rate was—

0	5	16	27	51	49 %	37

Akilshaw.—This was a large village near Shahpur. There were innumerable excavations both within and outside the village, but very little standing water. The subsoil water was 15 feet from the surface. The epidemic figure was only 3. The spleen rate was—

0	2	47	16	34	66 %	36

Nathuwal.—This village lies in the neighbourhood of the river but on comparatively high land. The subsoil water was 11 feet from the surface. The epidemic figure for October 1908 was 1. The spleen rate was—

0	0	32	8	60	40 %	25

Kandan.—This village was situated on low-lying ground close to the river Jhelum by which it had been flooded in 1908. The epidemic figure for October 1908 was 30, and as in October the deaths numbered 30 whilst the population of the village at a liberal estimate was not above 1,000, the death rate must have been at least at a rate of 360 per mille. In the case of Nathuwal, distant one or two miles but on slightly higher land and distinctly a larger village, the deaths in October numbered only 5. In the neighbouring large village of Tankiwal (epidemic figure 1) with a recorded population of 1,355, the deaths numbered only 7 or about 60 per mille. There can be no doubt therefore that the village Kandan suffered from severe epidemic conditions, though its neighbours on very slightly higher ground did not. The conditions call to mind very strongly the little epidemic areas which in 1908 and 1892 are seen along the course of the large rivers in the western tracts of the Punjab. Very few children could be obtained, but those examined showed spleen rate as below—

0	0	29	23	47	53 %	17

Among 10 adults only one had enlarged spleen. The subsoil water in the village was 8 feet from the surface.

Wegowal and Sardarpur.—The situation of these villages have been referred to. Approaching them from Shahpur the country was noticeably more waterlogged, and in the neighbourhood of Wegowal the subsoil water was at a depth of only 4 feet. The villagers informed us that the water which lay about was the result of flooding from an inundation canal. The spleen rate was—

0	31	26	10	32	68 %	19

Dharima.—Though this village is in the Sargoda thana it will be convenient to describe it here. At Wegowal we have noted that the subsoil water was only four feet from the surface. Two miles further east the Bar country is reached and water is at a depth of 20 feet from the surface. At Dharima a little further on, it is at an even greater depth. The village is a straggly one on irregular ground which is dry and arid looking in the extreme. The epidemic figure of the village was 4 and the spleen rate—

3	6	18	21	51	49 %	33

II.—Villages of the Bhalwal and Kot Momon Thanas.

The Bhalwal thana lies immediately to the south of the thana of Bhera, the line of junction of the two corresponding to the edge of the riverain. Whilst Bhera is almost all riverain land, Bhalwal lies within what is called the Bar.

To the south lies the thana of Kot Momon which is wholly Bar country, the subsoil water being everywhere at a depth of 40 feet or more, and the country evidently only saved from being a desert by irrigation. To the east of Kot Momon lies the thana of Miani Gondal the high land of which is continued into the thana of Kutheila Sheikan in the Gujrat district. South of Kot Momon is Midh which lies largely in the Chenab riverain.

Mortality.

In October 1908 the different thanas showed a recorded mortality as follows :—

	Normal.	October 1908.	Epidemic figure.
Bhalwal	40	205	5·1
Kot Momon	40	94	2·3
Miani Gondal	51	93	1·8
Kutheila Sheikan	121	564	4·6
Midh	73	289	3·9

In the case of Bhalwal the village epidemic figures are high along the Bhera border but low elsewhere. In Kot Momon the figure is frequently unity or low, though one village Kot Raya is exceptional in having a figure of 20. In the latter thana we seem for the first time to have succeeded in getting an area not influenced by the epidemic.

Reaction of the area to Epidemic Conditions.

As a rule the thanas mentioned show very little, if any, increase of the normal average in October. But in 1903 the rates for Bhalwal, Kot Momon and Miani Gondal were doubled, whilst in Midh the deaths were slightly higher than in 1908. A distinct, though slight, increase is also noticeable in 1892, in 1900 and in 1901.

Conditions in the Villages Visited.

Bhalwal.—This village had an epidemic figure in October of 1. The subsoil water was at a depth of about 40 feet. The spleen rate was—

0	0	23	6	71	29 %	17

Dera Ali Tragger.—This village was a hamlet of Nabusha Bulu which is shown on the map lying against the Bhera thana. The land was beginning to fall towards the Jhelum but was still high, and the subsoil water was about 25 feet from the surface. The epidemic figure was 9. The spleen rate was—

0	0	25	42	33	67 %	12

Luliani.—This was a large village in the thana of Kot Momon with an epidemic figure of 2. It was surrounded by flat land with but few excavations, and the aspect of the country was very dry. The subsoil water was at a great depth. The spleen rate was—

0	0	0	21	79	21 %	19

Kot Momon.—This was another large village lying in the heart of the Bar country. The country was very dry, but many excavations were present around the village. The epidemic figure was 1. The spleen rate was—

0	0	0	0	14	0 %	14

Kot Raya.—This village, which it will be remembered showed an epidemic figure of 20, was unfortunately not visited, though it was afterwards found to be situated close to a part of the road where a leaking canal had flooded a considerable tract and near some sheets of water in which anopheles larvæ were seen in enormous numbers.

III.—Villages of the Sarghoda Thana. (*Vide* Map IV.)

This thana occupies a large portion of the Shahpur Bar country. It is a typical "canal" tract and its villages for the most part have been formed only since the introduction of irrigation. The subsoil water is at a great depth and the country resembles generally that about Bhalwal and Kot Momon.

Mortality.

One might have expected from the physical conditions of the tract that the mortality during the 1908 epidemic would have been low. As a matter of fact the

epidemic figure was 7. But the distribution of mortality (shown in Map 10) shows that this high rate was mainly due to villages around the borders of the thana, especially to villages lying close up against Jaurian thana, which it will be remembered was severely affected. Another group of villages with rather high figures lies to the south at the foot of the very peculiar isolated Karana hills which rise here suddenly from the plains to a considerable height. Unfortunately I was unable for want of time to visit any villages in this thana, but passing through in the train I was able to ascertain that the ground sloped rapidly downwards towards the severely affected villages Uttian and Lakh shown in the map; and the fact that these villages are designated by name rather than by numbers shows that they are old established villages, and suggests that as they existed prior to the canals they naturally occupied the lowest lying portions of the thana.

IV.—Conditions at Amritsar and Delhi during the Non-Epidemic year 1909.

Mortality.

The mortality returns of Amritsar for 1909 were studied in the same manner as those for 1908. The number of deaths after the large numbers dealt with in 1908 seemed absurdly small. In the month of October there were in the whole city only 570 deaths or a rate of 45 per mille. In Khazana (division 9) the deaths numbered only 88 or a rate of 60 per mille. In some of the other divisions and areas the returns were as follows :—

	October 1908.	October 1909.	Rate in October 1909.
Divisions 1, 2 and 3	835	102	35
Divisions 5 and 7	889	90	48
Divisions 6 and 8	387	78	43
Division 9	665	88	60
Divisions 10 and 11	916	125	43
Division 12	452	42	36
Not located including Division 4	54	45	..
Total	4,198	570	45

In the case of admissions to the Amritsar dispensary there was also very little increase during the fever season, the highest weekly admission being 100 as against 566 in 1908.

It is clear therefore that in this autumn there was no increase of mortality beyond that more or less normal in India. And the year as far as Amritsar is concerned may safely be considered a non-epidemic year.

Though no study of the statistics at Delhi has been made it may be stated that here also there was no serious mortality in 1909.

Spleen Rate and Parasite Rate.

A community in Khazana, the children of which were examined at intervals, gave in percentages the following results :—

	February 1909.	April 1909.	August 1909.	October 1909.	November 1909.
Infection over 100 . . .	2	..	3	5	4
Infection over 20 . . .	25	7	14	5	8
Infection over 5	16	7	23	16	19
Infection under 5 . . .	28	39	23	31	27
Negative	28	47	36	42	42
Total percentage . . .	72	53	63	58	58
Number of children . . .	36	28	42	38	26

The spleen rate in percentages among the same children were—

February	14	19	50	8	8	92 %
August	4	27	31	23	14	86 %
October	4	15	44	26	11	89 %
November	4	8	58	19	9	91 %
June 1910	0	5	29	38	28	72 %

These figures show that whilst there are fluctuations especially as suggested by the spleen rate in June 1910 after a very dry summer the spleen and parasite rate in this community was always high.

The spleen rate in Mahan Singh in February was 90 per cent. In August 1909 it was again exactly 90 per cent. In June 1910 it was 85 per cent. The rates in February 1909 and June 1910 compared in detail are in percentages—

2	14	41	33	10	90 %	70
5	15	42	23	15	85 %	60

The differences are very slight.

Delhi was visited in February 1910. At this time in Ward XI the spleen rate in percentages was as follows :—

20	25	40	15	0	100%	40

A small community of Dhobies in Ward IV also gave 100 per cent. spleen rate, the size of spleen being equally remarkable.

In Ward VI the spleen rate in November 1909 in percentages was—

2 2 37 21 37 63 % 48

So that in Delhi conditions as regards spleen rate were apparently as severe as when seen immediately following the epidemic.

V.—Conditions in the Villages of the Amritsar and Gherinda thanas in 1909 and 1910.

It was thought possible that although in a non-epidemic year the massed mortality figures for rural areas were low, there might still be villages exhibiting high epidemic rates, especially as the rainfall in the monsoon of 1909 was over the normal, and some extensive collections of water were seen.

Examination of the statistics of the Gherinda thana showed that at Atari in October 1909 there had been 9 deaths, whilst in October 1908 the number had been 35. At Mahawa, a village we have referred to as situated on low water-logged ground, the deaths in October 1909 were 3, whereas in October 1908 they were 58. At Kasel, a village with an epidemic figure in October 1908 of 16 and a recorded rate of 330 per mille, there were in October 1909 only 11 deaths or a rate of 32 per mille. Examining the returns to find any examples of villages with high rates, it was found that the only high epidemic figure reached in this thana were Neshta 5, Bhaini 5, and Nathupur 5, villages which in October 1908 had epidemic figures of 16, 8 and 18, respectively; otherwise, with the exception of two small villages whose figures were doubtful, the 71 villages of this tract uniformly showed a figure which was unity or at most 2.

As regards this thana then the year was a non-epidemic one; but the spleen rate at Atari in November was not perceptibly different from what it was after the epidemic of 1908.

All the facts we have brought forward merely show what one had learned to expect, namely, that though the spleen and parasite rate fluctuate somewhat, these values are more or less fixed for any given area, and the rates recorded in Chapters VI and VII, though they may have been enhanced by the epidemic, are not solely or even mainly the result of this condition.

When it is recollected that, even under the conditions seen in the thana of Kot Momon, villages still showed very considerable spleen rates, it is obvious that the Punjab is very differently situated as regards malaria to Egypt, in which out of 7,000 spleens examined by E. H. Ross[1] only 6·8 per cent. were enlarged, and that

[1] Quoted by Day and Ferguson. Annals of Tropical Medicine and Parasitology, Vol. III, No. 3, November 1909.

measuring malaria by spleen rates or the presence of parasites this disease is always very prevalent in the Punjab.

But though malaria is always present and in a sense may be extremely intense as for example we have seen in parts of Delhi, the disease is only associated with high epidemic mortality under certain conditions.

It is probably quite evident by now that this distinction of epidemic or mortality producing malaria from the ordinary endemic condition is very important.

CHAPTER IX.

Epidemic and Endemic Malaria.

I.—Distinction between Endemic and Epidemic Malaria.

Before going further we should clearly appreciate the importance of this "mortality causing" or speaking generally "virulent" type of malaria as distinct from endemic malaria, and realise that in the investigation of malaria in the Punjab we have to consider not only the conditions associated with mere transmission of malaria which resemble as will be seen those frequently described in different parts of the world, but even more urgently to ascertain what are the causes of the peculiar epidemics, which as we have seen are such a prominent feature of this province. The most essential characteristic of the condition is the mortality with which it is associated. Indeed to measure fulminant malaria we have at present only one criterion, namely, the degree of mortality which results from it.

A high degree of endemic malaria we have seen may on the contrary co-exist with a more or less normal death rate.

Probably with severe endemic malaria there is a certain amount of increased mortality. But whatever the effect of endemic malaria upon mortality may be, it is the epidemic and especially the fulminant type of the disease which most severely affects the Punjab and which alone forces itself upon the public notice, so as to cause comment and alarm.

In "epidemics" in fact we see the instrument by which malaria attacks the Punjab and possibly part explanation of the fact that the recorded death rate from "fever" for this area, contrary to what one might have expected, is higher than that of the more tropical and one might have thought more malarious southern portions of India.

When we talk of malaria ridden tracts we must know clearly what we are referring to, whether the decrease of the population is inherent in the region or due to the chance involvement in the area of an epidemic or several epidemics following one another. We shall see more of the relation between the two conditions later.

II.—Relation between Epidemic and Endemic Malaria.

If we investigate the frequency with which different portions of the Punjab are affected with severe epidemics of malaria, we see at once that the western half or comparatively rainless portion of the Punjab is relatively unaffected.

Passing eastwards we come to a tract we have called elsewhere the Northern Epidemic Area and which, in the forty years or so for which we have data, has

suffered from no less than four great epidemics as well as a number of less severe ones. Still further eastwards over the Central Epidemic Area we again have records of three or four great epidemics. In the Southern Epidemic Area about Delhi there is a falling off in the number of epidemics, only two major epidemics having previously affected this tract. If we continue further eastwards into the United Provinces we find, as we have already noted, that in 1908 this Province suffered severely. But we shall find now that epidemics of great magnitude occur with nothing like the frequency they do in let us say the Northern Epidemic Area in the Punjab. In fact no epidemic of similar magnitude to that of 1908 appears to have been recorded in the United Provinces.

We may remember also that even this epidemic affected only the western half of the United Provinces. If we refer to the records of rainfall, we find that here the explanation of the relative infrequency of epidemics cannot be due to lack of rain, and in 1908 the eastern portion which was unaffected received not only more rain than the western portions but an even greater excess over the normal (*vide* maps comparing rainfall and fever given in the report of the Sanitary Commissioner with the Government of India, 1908).

Again if we map out roughly, by means of information given in the Gazetteers, the relative areas under cultivation for wheat and rice respectively, we find a very curious relation to epidemic prevalence. The rice land, which one might expect to be the more malarious, marks on the contrary the limit at which epidemic conditions cease. If we look for the reason why rice is cultivated instead of wheat, we find that the limit of rice cultivation follows roughly the line of about 30 inches average rainfall and an isotherm of increased average temperature, both conditions we might reasonably expect to favour malaria.

At this stage we may well ask ourselves whether this liability of the Punjab to epidemic malaria is not simply due to the fact that its inhabitants are less protected by immunity than are those of some other areas. If so we should certainly expect areas in the Punjab normally with a high endemic prevalence to show during epidemic times relatively less effect than more healthy areas. But at Amritsar the portions of the city worst affected by epidemic mortality were those we have reason to believe are permanently most subject to endemic malaria. At Delhi the same relation holds good, Wards most affected in the epidemic are normally the most malarious. These being cities it is possible that this selection by epidemic malaria of the localities most affected by endemic malaria is due to the protection enjoyed by the inhabitants of the central portions of the city. But in exactly the same way we find in the Gherinda and Amritsar thanas the epidemic conditions attacking not the least but the most malarious villages. The low-lying swampy villages like Mahawa and Gumtala do not escape, but are the most severely affected.

In Bhera thana it is those villages nearest the river which suffer most. In Shahpur thana the villages where the conditions are most suitable for endemic malaria and on the whole the villages which show the highest spleen rate are the most affected by epidemic mortality. In Gujrat the same relation is seen; the affected villages are the most low-lying and have the highest spleen rates.

The form of epidemic malaira we are discussing would then appear to be not the antithesis so much as the outcome of endemic intensity. But a closer scrutiny of observations shows that in reality the two conditions are not interdependent, though it would seem that on the whole villages in which the conditions favour endemic malaria are more exposed to epidemic conditions.

This want of accurate relation will be evident from the following instances described more in detail in previous chapters—

Villages.	Spleen rate.	Epidemic figure October 1908.
Nathowala	40	1
Kandan	53	30
Akilshaw	66	3
Dera Ali Tragger	67	9
Atari	81	5
Shadiwal	42	25
Kuthala	75	27

What the condition of the spleen rate is in the rice growing portions of the United Provinces I do not know. But in the western portions of the Punjab, which we have seen are beyond the limit of normal epidemic prevalence, there is no lack of endemic malaria. Multan I have frequently heard referred to by medical officers as being a place in which enlargement of the spleen was quite common, and Captain Brown, I.M.S., who sends me the result of the examination of 273 children at Dera Ismail Khan, finds the spleen rate in this place to be 75 per cent.

The amount of endemic malaria roughly speaking depends upon one set of conditions, that of epidemic malaria upon another. Very largely for these reasons I have insisted on the relative independence of the two conditions. The essential similarity of the nature of epidemic and endemic malaria will be discussed later.

III.—Effect upon the Population.

Perhaps for the time the most important thing for us to grasp is the effect of the two kinds of malaria upon the population.

If we take the total death rate in the whole Punjab from non-epidemic fevers, we shall find that in round figures it is about 30,000 per month. In a year we should get 360,000 deaths from non-epidemic fevers, including such diseases as tuberculosis and many others; in fact this number would practically represent the residue of deaths from all causes after abstracting a certain number of deaths recorded as plague, small-pox, dysentery, etc.

In 1908 an equal number of deaths occurred in two months from epidemic malaria alone. In Gurgaon district, which normally loses from non-epidemic diseases about 17,508 persons in the year, there occurred in the month of October 1908 no less than 15,740 deaths or nearly as many people as would have died in a whole year from non-epidemic disease. Sialkot, which normally loses about 3,000 a month from non-epidemic disease, lost in October 1890 33,609 persons and in October 1892 20,972. Gurdaspur, which normally loses about 2,000 a month, lost in October 1890 11,976, in October 1892 18,921 and in October 1894 10,551 persons. Umballa, which normally loses about 1,500 a month, lost in October 1890 17,025 persons.

Causes such as famine are usually supposed to exert the greatest influence on increase of population and this may possibly be the case even though the actual deaths do not equal those due to epidemic malaria. But for actual mortality (excepting plague) there is no other cause in the Punjab to approach that of the disease we are discussing. We shall understand this better when we endeavour to explain the causes underlying these epidemics.

PART III.

DETERMINING CAUSES OF EPIDEMIC AUTUMNAL MALARIA.

CHAPTER X.

Anopheles of the Punjab.

In the first volume of Theobald's Manual of the Culicidæ published in 1901, the only species of anopheles mentioned as having been recorded from the Punjab is *N. fuliginosus* (Giles). In 1902 Stephens, Christophers and James record *M. rossi* (Giles) and *M. culicifacies* (Giles) as the two common species at Mian Mir near Lahore, whilst the same observers in the same locality obtained *M. barbirostris* (Van der Wulp), *C. pulcherrima* (Theobald) and *N. stephensi* (Liston), the latter two species being then new to science. James also records from the neighbourhood of Lahore *N. fuliginosus* and *N. maculatus* (Theobald). A single specimen sent by me from Lahore is recorded by Theobald as *M. minutus* (Theobald), whilst another single specimen also sent by me still forms the only example of Theobald's species *M. leptomeres* (Theobald). At Ferozepore, about sixty miles to the south of Lahore, Adie[1] records *M. rossi, M culicifacies, N. fuliginosus, N. stephensi, C. pulcherrima, M. turkhudi* (Liston), *M. sinensis* (Wied), *M. barbirostris, N. jamesi* (Theobald), and *N. maculipalpis* (Giles). He also calls attention to a variety of *N. fuliginosus* peculiar to the cold months.

Thomson[2] from Dehra Dun at the foot of the hills just outside the borders of the Punjab to the east records the common species as *M. rossi, M. culicifacies* and *N. maculatus*, whilst the following species also occur, *A. lindesayi* (Giles), *M. nigerrimus* (James and Liston), *N. fuliginosus*, N. *theobaldi* (Giles), *M. christophersi* (Theobald), *N. maculpalpis* (Giles), *N. indica* (Theobald) and *C. pulcherrima*. This as we shall see represents both a plains and a hill fauna.

In the hills *A. lindesayi* is recorded by Giles as early as 1900. It occurs as we have seen at Dehra Dun. It is also recorded from Bakloh and Simla 6,000 feet (James and Liston).

From Kangra Theobald records as taken by Dudgeon *Neocellia dudgeoni* (Theobald), probably the same species as James's *N. willmori* (James). From Kashmir are recorded *N. willmori* and *M. turkhudi*. From Quetta beyond the Suliman range two new species of the genus *Pyretophorus, P. nigrifasciatus* (Theobald) and *P. nursei* (Theobald) together with another species of *Neocellia, N. intermedia*

[1] Adie, Mosquitoes and Malaria in Ferozepore. Indian Med. Gazette, January 1905.

[2] Thomson, Mosquitoes and Malaria in Dehra Dun. Jour. Royal Army Med. Corps, May 1903.

(Rothwell) have been taken by Major Nurse who also records from the same district *M. rossi* and *M. culicifacies*.

M. rossi.—I have found during its season in profusion at Delhi in the extreme south-east, at Umballa and Amritsar in the central portion of the submontane tract, and at Gujrat and Bhera to the north-west. Taking into consideration also Adie's observations at Ferozepore and the experience of some other observers, there can be little doubt that this species is during its season the commonest anopheles throughout at least the eastern half of the Punjab.

The common anopheles at Dera Ghazi Khan in September was, I am informed by Major Perry, I.M.S., *C. pulcherrima*, whilst Captain H. C. Brown, I.M.S., also speaks of this species as the commonest species at Dera Ismail Khan. It is possible that towards the west, where the monsoon rainfall is only a few inches, *M. rossi* does not flourish to the same extent as further east; but observations are required on this matter.

M. culicifacies.—Though it never or very rarely occurs in such profusion as *M. rossi* is a very common mosquito and is found not only widely distributed throughout the Punjab but also at almost all times of the year. I have found *M. culicifacies* abundant at Palwal, Delhi, Umballa, Ghagger, Beas, Ferozepore, Amritsar and Atari. Captain Brown, I.M.S., states it is very common at Dera Ismail Khan.

N. fuliginosus.—I have found abundant at Delhi, Armitsar, Lahore, Gujrat and Ferozepore. It is like the two preceding species common throughout most of the Punjab.

N. stephensi.—I have taken at Delhi, Umballa, Beas, Amritsar, and Lahore. At Delhi this species is found in enormous numbers in the wells of the city, several hundred larvæ being brought up by a single cast of the net. Its larvæ also swarm in pools in the river bed of the Jumna and elsewhere. As noted by Dr. Bentley in the case of Bombay the adults which hatch out from larvæ taken in the wells are small. Specimens bred from open pools are so much larger that it is difficult at first to believe that they can be the same species. But I have not been able to note any marked differences other than in size. Adults hatched out from nymphs taken on the river bed at Beas in February were small like those from the wells at Delhi. At Amritsar the species is chiefly found in pools. It occurs also in wells about the outskirts of the city but not as at Delhi in large numbers.

C. pulcherrima—Which at the time of its discovery seemed to be almost peculiar to Lahore is evidently a common Punjab species. I have found it sparingly at Delhi, Beas, Amritsar, Atari and Lahore.

M. barbirostris.—I have taken at Atari, Amritsar and at Delhi. It is found in large open wells, but as a rule single larvæ only are captured. Colonel Adie,

I.M.S., tells me he has had the same difficulty in finding more than a few isolated specimens at Ferozepore.

M. nigerrimus (James and Liston).—I have found rather more frequently than *M. barbriostris* but never in large numbers. As already noted a specimen of this species sent from Lahore was termed by Theobald *M. minutus*, and if this name is to be used the specimens taken recently by me at Delhi and Amritsar would be *M. minutus* as they agree with Theobald's description of this species. The differences, however, between *M. minutus* and *M. vanus* (Walker) are extremely small, the only differences noted by Theobald being that the two wing spots in the first species are white while in the second they are yellowish. Again the type specimen of *M. nigerrimus* (Giles) according to Theobald has the tips of the palpi black, otherwise it resembles *M. vanus*. Size in the case of mosquitoes depends very largely upon conditions under which the larvæ has lived and has but little value as a specific character, also the name "minutus," though it may be appropriate to the particular specimen sent home, is very out of place as applied to the species under discussion which is noticeable among other anopheles of the Punjab for its large size. The name *M. nigerrimus* (James and Liston) seems to avoid these difficulties.[1] The *M. nigerrimus* (Giles) with the black tipped palpi I have not encountered.

M. turkhudi—Is a species not often taken and about whose habits not much is known. I have found it in the bed of the Ghagger where this river first leaves the foot hills (Siwaliks) for the plains, in the bed of the Jumna at Delhi, and in large numbers in the bed of the Beas. It seems indeed almost restricted to the beds of rivers, for out of many thousands of larvæ obtained during February nnd March from pools, jheels and elsewhere this species was not represented, though abundant at this time in the river beds. It is found not only in pools but is very fond of places where water is oozing in a layer from the sand, especially if the sand has become covered with the growth of alga. Under such circumstances one can understand that the larvæ do not require the palmate hairs, which in this species are rudimentary. *M. turkhudi* is a very large mosquito and its larvæ especially are noticeable on account of their great size and their stoutness when full grown.

Curiously enough this species was also found near the origin of a hill stream at a height of between 4,000—5,000 feet near Kasauli. Finding it in this situation I suspected that the specimens might be *P. nigrifasciatus*, but the scale structure was identical with that seen in specimens of *M. turkhudi* from the plains.

A. lindesayi.—I have found in large numbers in the streams about Kalka at a height of 1,500—3,000 feet and at Pathankot. It is evidently a common hill species.

---

[1] *Vide* the new edition of James and Liston's Anopheles of India.

Neocellia willmori occurs in profusion both at Kalka and also near Kasauli at a height of 4,000—5,000 feet. It is also to be found in the torrent beds at the foot o the Kalka hills as far down as Chandigahr ; but at Ghagger where the river bed has become sandy I no longer found this species. *N. willmori* is equally common at the foot of the hills at Pathankot about 100 miles to the north-west of Kalka. A single specimen of this species is stated by Theobald to have been sent by me from Lahore. It is probably one of the commonest hill species and may possibly be sometimes found at some little distance from them.

N. maculatus.—I have found abundantly at Pathankot. James and Listen record this species from Lahore in March and April.

N. maculipalpis.—I have obtained in small numbers at Chandigahr below Kalka and fairly abundantly at Pathankot. Adie records it as rare at Ferozepore.

N. indica.—I have taken at Chandigahr in considerable numbers along with *N. willmori.*

Roughly speaking on the plains *M. rossi, M. culicifacies, N. fuliginosus, C. pulcherrima* and *N. stephensi* are common species everywhere, whilst *M. barbirostris, N. nigerrimus* are generally found if systematic search be made, and *M. turkhudi* if the pools in the bed of a large river are examined. The species *M. maculatus, M. willmori* and *M. maculipalpis* are rare on the plains.

On the hills it is evident we have a very distinct fauna. A peculiar feature is the number of speckled species closely resembling one another. Thus *N. willmori, N. indica, N. maculatus, N. maculipalpis, N. theobaldi* all very closely resemble one another in their general appearance and are all found in small stony streams among and at the foot of mountains. The dominance of the genus *Neocellia* is also worthy of remarks.

The species one might have expected to find in the streams at the foot of the hills, namely *M. listoni,* appears to be rare, a circumstance the more noteworthy as at the foot of the eastern Himalayas it is the commonest stream breeding species.

The large number of species found and especially the large number of common anopheles to be found at any one place in the Punjab is very striking

II.—Seasonal Prevalence of Anopheles.

During the cold weather when the night temperature may reach as low as 50°F., the larvæ of anopheles are not found in open pools but occur only in permanent waters containing much aquatic vegetation ; even in this situation larvæ are scanty during December and January.

The first to note the species found under these circumstances and accurately to follow the course of events during the winter was James. He notes that the

number of adult insects in the houses decrease during November, and that the species *M. rossi* completely disappear, neither adults nor larvæ being found after the end of November. In the case of *M. fuliginosus* and *C. pulcherrima* on the contrary adults were to be caught in reduced numbers in suitable places throughout the winter and these species continue to lay their eggs and to go through their metamorphoses as usual. *M. culicifacies* was found to pass the winter in the larval stage in which form it appeared to hibernate, the larvæ being sluggish in their movements and growing very slowly if at all.

At Ferozepore Adie notes that *N. fuliginosus* is found throughout the year and *M. culicifacies* very nearly so. *M. rossi* does not appear until July and disappears by December. *M. culicifacies* is common from about the first of May and disappears about the end of December. *N. stephensi* comes in about May and disappears about the middle of November. The common species as a whole are most numerous in September.

My own observations on seasonal prevalence have been made chiefly at Amritsar, but they have been supplemented by less complete observations elsewhere.

During the winter months *N. fuliginosus* was found breeding in large weedy tanks to the north of the city, also in similar positions in the surrounding country. Along with this species but in much smaller numbers was found *C. pulcherrima*. In a large tract to the south of the city, where there were no large permanent sheets but numerous pits and pools containing little or no weed, no anopheles larvæ were found breeding. The larvæ of *M. culicifacies* were first found at Amritsar in March, but the species was breeding in profusion in February at Atari, 15 miles away, where there were some very extensive and suitable breeding places. The species was also found breeding at Beas and in the bed of the Ghagger at this time. *N. stephensi* was first found in small numbers at Amritsar towards the end of February, but this species was breeding in immense numbers in the wells and elsewhere at Delhi at this time and was in fact the commonest species found there. *N. stephensi* was also found in considerable numbers at Beas. At Atari in February not a single specimen was found after much search. But the species was abundant in March both at Amritsar and at Atari. At Kalka in February *N. willmori* and *A. lindesayi* were both abundant in pools in the stream beds, and at Chandigahr a few specimens of *N. maculipalpis* and of *N. turkhudi* were found.

By March the weather has become considerably warmer. At this time adults of *N. fuliginosus, C. pulcherrima, M. culicifacies* and *N. stephensi* were found quite commonly and their larvæ occurred in profusion in almost every suitable situation. But open pools free from weeds were still free from larvæ.

With the increasing warmth of April a still further increase of the spring species took place and in parts of Amritsar as many as a hundred adult *N. fuliginosus* could

sometimes be caught in a single suitable shed. Along with these there were always a smaller number of *C. pulcherrima*, *M. culicifacies* and *N. stephensi*. In the south portion of Amritsar (Hakiman), though it is one of the most malarious portions of the city, anopheles were not so numerous, the reason evidently being that there were no suitable sheets of water in the neighbourhood. At Delhi also in this month, though larvæ were found in profusion in the river bed and in parts of the Civil Station, adults were caught with difficulty even in the outlying portions of the city.

In the villages the conditions vary. In the drier ones a few anopheles only, usually *N. fuliginosus*, *N. stephensi* and *M. culicifacies*, are to be caught; in these villages which have large sheets of water near them almost all the species mentioned abound.

Up to April the increasing temperature has evidently favoured the propagation of the genus, but its continuation in the absence of rain by causing a progressive desiccation of breeding places now begins to act in a hostile manner. At this time it is no uncommon thing to find swarms of larvæ, even those of *N. fuliginosus*, in small almost dried up and very foul pools.

During June the few pools left are as a rule very unsuitable for breeding, and not infrequently it may be difficult to find anopheles larvæ in any particular neighbourhood. Adult anopheles are also reduced in number. At Hakiman, after an unusually dry summer (1910), only three specimens of anopheles were caught after searching for some time. At Gurba Singh, where six weeks previously hundreds were to be caught, only seven were found in a search at this time. All were extremely small specimens, scarcely half the size of those found at more favourable times.

Under such conditions the monsoon breaks and there is thenceforth a remarkable change; for within a few weeks of the first fall of rain anopheles are again found breeding in the utmost profusion everywhere.

So long as rain continues at short intervals these conditions are maintained, with the result that there is an enormous and progressive increase in the numbers of anopheles which far exceeds the increase of the spring; and instead of larvæ being chiefly confined to large collections of water, such as tanks and sluggish weed grown channels, they are now found in every situation where water remains any length of time.

The species which come into prominence at the time of this enormous and phenomenal increase of anopheles connected with the monsoon in the Punjab are *M. rossi* and *M. culicifacies*. *N. fuliginosus*, the common mosquito of the spring, is now comparatively rare.

In 1909 *M. rossi* was not found at Amritsar until the end of June. Yet during the spring of 1910 I had occasion to breed out many thousands of larvæ caught

sometimes be caught in a single suitable shed. Along with these there were always a smaller number of *C. pulcherrima*, *M. culicifacies* and *N. stephensi*. In the south portion of Amritsar (Hakiman), though it is one of the most malarious portions of the city, anopheles were not so numerous, the reason evidently being that there were no suitable sheets of water in the neighbourhood. At Delhi also in this month, though larvæ were found in profusion in the river bed and in parts of the Civil Station, adults were caught with difficulty even in the outlying portions of the city.

In the villages the conditions vary. In the drier ones a few anopheles only, usually *N. fuliginosus*, *N. stephensi* and *M. culicifacies*, are to be caught; in those villages which have large sheets of water near them almost all the species mentioned abound.

Up to April the increasing temperature has evidently favoured the propagation of the genus, but its continuation in the absence of rain by causing a progressive desiccation of breeding places now begins to act in a hostile manner. At this time it is no uncommon thing to find swarms of larvæ, even those of *N. fuliginosus*, in small almost dried up and very foul pools.

During June the few pools left are as a rule very unsuitable for breeding, and not infrequently it may be difficult to find anopheles larvæ in any particular neighbourhood. Adult anopheles are also reduced in number. At Hakiman, after an unusually dry summer (1910), only three specimens of anopheles were caught after searching for some time. At Gurba Singh, where six weeks previously hundreds were to be caught, only seven were found in a search at this time. All were extremely small specimens, scarcely half the size of those found at more favourable times.

Under such conditions the monsoon breaks and there is thenceforth a remarkable change; for within a few weeks of the first fall of rain anopheles are again found breeding in the utmost profusion everywhere.

So long as rain continues at short intervals these conditions are maintained, with the result that there is an enormous and progressive increase in the numbers of anopheles which far exceeds the increase of the spring; and instead of larvæ being chiefly confined to large collections of water, such as tanks and sluggish weed grown channels, they are now found in every situation where water remains any length of time.

The species which come into prominence at the time of this enormous and phenomenal increase of anopheles connected with the monsoon in the Punjab are *M. rossi* and *M. culicifacies*. *N. fuliginosus*, the common mosquito of the spring, is now comparatively rare.

In 1909 *M. rossi* was not found at Amritsar until the end of June. Yet during the spring of 1910 I had occasion to breed out many thousands of larvæ caught

in different places in the Punjab and though every other species was represented no larvæ of *M. rossi* were taken. In April many hundreds of adults were collected from the houses in all parts of the city and specimens of all the plains species except *M. turkhudi* were found, but not a single specimen of *M. rossi* was among them. At Delhi in April though anopheles were not abundant, specimens of all other species were obtained, but there were no *M. rossi*. Such complete disappearance of the commonest of all the species for so many months is very remarkable.

In regard to *N. fuliginosus* we again have a very clearly defined tendency to a marked seasonal prevalence. This species being, as Adie described it at Ferozepore, the common cold weather anopheles. Its period of greatest preponderance is unconnected with the monsoon and depends largely upon the amount of water left standing from the previous year and showers falling in the early months. It shows little tendency to increase until the season for the autumn species is passing away.

The species *C. pulcherrima* follows the habits of *N. fuliginosus*, but in the eastern portion of the Punjab is relatively unimportant. Its seasonal prevalence in the western districts requires to be worked out.

N. stephensi in Amritsar, Atari, Beas and Delhi is a species which comes into prominence in the early summer. And though it is found at other times of the year it does not seem to increase much in the autumn.

Upon *M. culicifacies* further observations seem called for, especially in view of the great importance this species possesses as the chief carrier of malaria in the Punjab. In 1909 the numbers of *M. culicifacies* at Amritsar in the autumn certainly underwent no rise at all comparable with that of *M. rossi* at this time. I have found the adults of this species in fact as numerous in April as at any time of the year. The larvæ of *M. culicifacies* however at Mian Mir undoubtedly underwent an increase which commenced in August and continued throughout the autumn. The numbers caught in Delhi were also highest in October.

With the cessation of the rain the land more or less rapidly dries, the smaller pools disappear and the pits and more permanent collections of water only remain as breeding places. It is very noticeable that under these circumstances in the absence of fresh rain many pools cease to be suitable for breeding and the number of larvæ therefore tends to be diminished out of proportion to the extent of desiccation.

Adults however continue to be caught in very large numbers even though breeding places are greatly reduced and larvæ scanty. *N. fuliginosus*, *N. stephensi* and *M. culicifacies* still retaining about the same prevalence for a time again assume relatively greater prominence with the disappearance of *M. rossi*. But in October the night temperature begins to fall considerably and by November the

average is usually under 60°F. In December it has fallen to 50°F. or thereabouts and the cold weather conditions we have described supervene.

III.—Permanent Breeding Places.

Probably the best general division of breeding places is that used by Dr. Bently in regard to the breeding places in Bombay city. This division is into :—

(*a*) Permanent.
(*b*) Temporary.

Permanent breeding places in the Punjab are often more important as a means of enabling a species to maintain itself through periods of drought than as a source of malaria.

During the months May and June anopheles are put to great stress. A morning's search for example in June 1910 in one of the most malarious parts of Amritsar yielded only three anopheles and no breeding places were found in the neighbourhood.

And to the west of Delhi city on the land away from the neighbourhood of the river I failed in April to find even a single source of anopheles. Similarly in November only one place was found in which a few larvæ were present. But however hard pushed the genus may be as a result of drought we can generally find some place in the neighbourhood where the different species are breeding more or less freely. At Delhi for example *N. stephensi* and *M. culicifacies* were found breeding freely in the bed of the Jumna. At Amritsar anopheles were still abundant in certain tanks to the north of the city long after they have become greatly reduced elsewhere. At Atari a series of excavations filled with water have always yielded several species no matter what time of the year they were visited. When suitable temporary breeding places form in the neighbourhood of permanent breeding places a species can at once extend itself over a wide area. A large permanent source of anopheles may exert in fact a very important indirect effect, as is shown by Dr. Bentley for Bombay, by its power of at once stocking temporary breeding places. Thus at Delhi it is reasonable to believe that in the case of rain falling and creating numerous temporary breeding places the species would propagate themselves in greatest numbers first in the areas bordering the river, and this might explain to some extent the distribution of malaria in the city without our having to suppose that the Jumna bed was the source of the actual anopheles which reached the city. In Amritsar small pools on the outskirts were immediately stocked with larvæ, but further within the city they remained often a fortnight or more without becoming infected, there being no adults at the time in the neighbourhood to make use of them.

In a country so dry and so exposed to drought as the Punjab, large areas in which anopheles can continue to exist, however adverse the conditions be elsewhere,

are thus important and may almost be termed anopheles sanctuaries. The following conditions in the Punjab may be considered as always acting to a greater or less extent in this way—

(1) Large river beds like that of the Jumna, Beas, etc.
(2) Jheels and large tanks filled with aquatic vegetation with their associated swamps and pools.
(3) Extensive brick fields and large excavated tracts such as exist near most large towns and even some villages.
(4) Irrigation systems.

Apart from such sources larvæ of anopheles are not abundant in the dry months. That a particularly dry year seems to exert no permanent reduction in the genus is rather grimly shown later when we discuss the effect of "dry" years upon malaria. (*Vide* Chapter XIII.)

IV.—Temporary Breeding Places.

During and after the rains when breeding of most species is at its maximum the chief sources of anopheles are—

(1) Pits and excavations which surround almost every village and town.
(2) Shallow accumulations of rain water.
(3) Irrigation channels.
(4) Other miscellaneous sources.

The larger pits contain water all the year round but are more often than not unsuitable for breeding purposes and no larvæ are found in them. The small pools whose numbers may be great during the rains are undoubtedly the most important source of *M. rossi*.

Of all sources during this time the second type are the most interesting. In some cases after the rains, sheets of water can be seen stretching for miles. In March, when investigating some sheets of water of this kind lying in the Gherinda thana, I was greatly struck with the numbers of anopheles such sheets must give rise to. The larvæ of *M. culicifacies* and of *N. fuliginosus* were in immense number everywhere quite irrespective of houses or any obvious source of food supply. It was also very noticeable that in the case of *M. culicifacies* the larvæ and the adults which hatched out from them were very large specimens suggesting that the conditions were peculiarly favourable to this species. When such waters last any time aquatic weeds very rapidly grow and for the time being a village may for all practical purposes come to be situated in a marsh.

In other cases very extensive sheets of water may be hidden in the grass and vegetation, and may escape notice unless search be made for such a condition, or acres of land may be covered with small puddles lying in furrows and invisible

even a few yards off, or again such collections may be of such a temporary nature as to seem unlikely to breed anopheles. But very commonly though a small shallow pool of this kind may appear to have dried up, it is surprising how often one finds on close inspection that one or two hoof marks of cattle or some other small hollows still contain a little water and that crowds of larvæ are here collected together. Even if the water entirely dries up the larvæ still retain, so long as the mud remains moist, the power to continue their development when more rain falls. One may thus find pools of a very temporary nature acting as important breeding places.

The part played by irrigation channels is well shown by the work done at Mian Mir in 1901—03. The number of larvæ of *M. culicifacies* after August was always very great; so much so that, as this species was not found breeding in any numbers in the pools, its breeding places were considered to be almost confined to the canals. But the abolition and filling up of the canals have not reduced the numbers of this species which was very numerous in October 1909. Very probably large numbers still breed in shallow rain pools such as I have described, many of them obscured by and hidden among grass. In addition to the breeding which goes on in the actual water channels there are often escapes in connection with canals which may be important breeding places. In the canal district south of the Jhelum, where apart from the canals there is practically no water, I found in one such situation so many larvæ of *M. culicifacies* that the edges of the pools appeared black and the larvæ formed a scum visible at a distance of several yards.

Many kinds of breeding places frequently mentioned as sources of anopheles are relatively not very important in the Punjab. Water near standpipes I have rarely found with more than at most a very few and usually small larvæ. Tins and receptacles also, though they may be found containing anopheles larvæ, are not an important source of anopheles in the Punjab.

Wells at Delhi are a source of *N. stephensi*, but at Amritsar the amount of breeding in wells seems almost negligible.

V.—Relative Proportions of Male and Female Anopheles.

The proportion of male and female adults caught has shown a constant relation to :—

(*a*) The distance of the breeding places.

(*b*) The absence or presence of breeding places.

At Amritsar males were found not to have penetrated to a greater distance than about 100 yards into the more solid portions of the town. Even beyond the first row or two of houses their numbers had already become reduced in comparison with that of the females. When breeding places had been reduced in

numbers (April to June) the proportion of males also diminished and in June nearly every anopheles caught was a female.

The following tabulated statement of recorded catches illustrates this point:—

	Anopheles caught in houses on the immediate outskirts of Amritsar.	Anopheles caught in a zone lying interior to the extreme outskirts.
March.		
(*a*) At Hakiman with few or no breeding places in the neighbourhood.		
N. fuliginosus male	0	No anopheles found.
,, female	11	
N. stephensi male	1	
,, female	1	
(*b*) At Jalewlayan many breeding places.		
N. fuliginosus male	35	*N. fuliginosus* male 0
,, female	44	,, female 21
(*c*) Houses immediately behind above.		
N. fuliginosus male	10	
,, female	37	
April.		
Breeding places disappearing.		
N. fuliginosus male	9	*N. fuliginosus* male 1
,, female	38	,, female 103
M. culicifacies male	3	*M. culicifacies* male 0
,, female	15	,, female 3
N. stephensi male	3	*N. stephensi* male 0
,, female	6	,, female 4
C. pulcherrima male	0	
,, female	2	
June.		
(*a*) Before extensive breeding places formed by rains.		
N. fuliginosus male	0	*N. fuliginosus* male 0
,, female	6	,, female 1
M. culicifacies male	0	
,, female	4	
N. stephensi male	0	
,, female	9	

(*b*) After rains had started.

N. fuliginosus	male	. . . .	2	
,,	female	. . . .	10	
M. rossi	male	. . abundant		*M. rossi* male . . . 1
,,	female	. . ,,		,, female 29

NOVEMBER.

N. fuliginosus	male	. . . .	1
,,	female	. . .	49
M. culicifacies	male	. . . .	0
,,	female	. . . .	2

Anopheles caught at Delhi near breeding places:

APRIL.

M. culicifacies	male	. . . .	2
,,	female	. . . .	3
N. stephensi	male	. . . .	1
,,	female	. . . .	2

Anopheles caught in the town away from any local breeding places:

NOVEMBER.

N. fuliginosus	male	. . . .	0
,,	female	. . . .	6
M. culicifacies	male	. . . .	1
,,	female	. . . .	11
N. stephensi	male	. . . .	0
,,	female	. . . .	3
M. rossi	male	. . . .	0
,,	female	. . . .	4

Though these observations show that in towns the males penetrate only a short distance, they do not necessarily show that males are confined to the immediate neighbourhood of breeding places. At Atari males were numerous in the village though this was at a distance of 400 yards from the breeding places. They therefore seem able to traverse considerable distances in the open.

VI.—SPECIES OF WHICH THE ADULTS ARE FOUND IN THE OPEN.

At Atari it has been mentioned that there exist extensive breeding grounds. These consist of excavations perennially filled with water which is for some reason always in a state very suitable for breeding. In the beginning of November 1909 there were no other important source of larvæ than the pools referred to. In these the most numerous larvæ were those of *M. rossi*. Larvæ of *N. fuliginosus* and *C. pulcherrima* were also present in large numbers.

In the evening anopheles could be seen hatching out from the pupal skin and after resting a short time flying off to the low bushes which grew at the edge of the water.

During the day therefore various bushes and tufts of grass which lay on the plain around this source of anopheles were covered with a large mosquito net and beaten vigorously with a stick. (It was found difficult to dislodge mosquitoes during the day but easier towards evening.)

Immediately on the banks the result of a number of beatings yielded—

M. rossi	male	13	
,,	female	5	None contained blood.
C. pulcherrima	male	1	
,,	female	2	Both were fully gravid, neither containing blood, *i.e.*, they were on the point of oviposition.
N. fuliginosus	male	0	
,,	female	1	Fully gravid, no blood in the gut, *i.e.*, it was on the point of ovipesition.

This operation of beating bushes, etc., was then carried out over a wider area. Between the breeding place and the village, on what seemed a dried and sunbaked plain with little or no shelter, the following yield was given :—

N. fuliginosus	male	2	
,,	female	7	5 specimens contained recentm ammalian blood and the ovaries more or less developed. 1 contained old blood, the ovaries nearly fully developed. 1 containing no blood, the spermatheca was empty and the ovaries undeveloped.
C. pulcherrima	male	2	
,,	female	1	No blood, ovaries undeveloped.
M. rossi	male	1	

Anopheles were in this case found not only in small bushes and in tufts of tall grass but in a low scrubby plant growing somewhat like heather and even small depressions in the ground formed by the partial sinking in of some recently-made graves.

In a direction away from the village and away from any other houses at a distance of 500 yards from the breeding place the catch was as follows :—

M. rossi	female	1	No blood in gut, undeveloped ovaries, spermatheca empty, glands immature.
N. fuliginosus	female	2	1 showed old mammalian blood in gut. Ovaries partly developed, spermetheca full. 1 showed no blood, ovaries fully developed.
C. pulcherrima	female	1	Recent mammalian blood, ovaries slightly developed.

It will be seen that except on the borders of the excavations the species *M. rossi*, though the commonest in its larval form, was not nearly so frequently found in the bushes, etc., as *N. fuliginosus*.

Of very great interest was the condition of the females caught in different places. Those caught away from the pools had in many cases blood in the gut and showed ovaries undergoing development just as would have been the case in anopheles caught in a village. Yet in this position it is difficult to see how they got any blood. The females of species other than *M. rossi* caught near the edge of the pool, being fully gravid and having got rid of every trace of blood, must have been ready at any moment to lay their eggs. It is reasonable to suppose that they had found their way back to the water for this purpose.

Up to the present no tests have been made as to the nature the blood found in these mosquitoes, but the fact that most of the females had succeeded in obtaining blood shows that the species *N. fuliginosus* and *C. pulcherrima* can live quite well even on a bare plain with a few tufts of grass and a few small bushes for shelter.

In the village a catch of anopheles gave—

M. rossi females 40.

There were also numerous males

and a few *N. fuliginosus*
and *C. pulcherrima*.

The females showed an ovarian formula indicating steady infiltration (*vide* next section).

VII.—Age Composition of Anopheles Communities.

The method of ascertaining the age of an anopheles and other bionomical facts regarding the genus will form the subject of a later report, but brief mention may be made of what I have termed the ovarian index of a community.

Roughly speaking there is an ovarian index characteristic of anopheles communities near active breeding places and corresponding with a high relative prevalence of males. There is another ovarian index characteristic of communities remote from breeding places or those existing after breeding places have disappeared, in this case associated with an absence of males or their occurrence in very small numbers.

A third type of communities exist in which large numbers of specimens are at about the same stage of development, but all stages are not represented. This seems to suggest the spasmodic flights of anopheles on particular nights.

VIII.—Relation to Malaria.

Of the long list of Punjab anopheles four species only, *M. culicifacies*, *N. stephensi*, *M. fuliginosus* and *N. maculipalpis*, have been recorded as having been

found in nature carrying the sporozoites of malaria. *M. culicifacies* was first shown to carry malaria at Mian Mir by the Royal Society's Commission ; *N. stephensi* is recorded by Liston and later by Bentley as actively concerned in the transmission of malaria at Bombay. The power of *N. fuliginosus* to carry malaria is shown by Adie who found one of 200 specimens dissected at Ferozepore with sporozoites. In this I am able to confirm Colonel Adie as sporozoites were found in this species from a village near Amritsar in April. It is worthy of note that at the same time the dissection of hundreds of this species caught in Amritsar city gave a negative result. Major Robertson, I.M.S., informs me that *N. maculipalpis*, which is the common species in the Terai below Naini Tal, also acts as a carrier in nature in this locality.

With the exception of *M. rossi* the power of the remaining species of anopheles in the Punjab to transmit malaria in nature is unknown.

Even more important than the question whether the rarer species transmit malaria or not is the question as to what part if any is taken by *M. rossi*. The results obtained with this species by Stephens, Christophers and James have been lately confirmed by Bentley who, dissecting *M. rossi* and *N. stephensi* caught together in Bombay, found the former with sporozoites and the latter entirely negative. But the very strongest evidence is required before this species can be considered never to act as a carrier.

IX.—Relation of Anopheles to Epidemic Conditions.

No actual observations as to the relative prevalence of anopheles during epidemic times exists. Enough has been said to show that this would be an extremely important subject of enquiry.

CHAPTER XI.

Rainfall and Temperature in Relation to Epidemic Malaria.

The statement is very generally made in the Punjab that following an unusually heavy monsoon, fever is especially prevalent. By this is meant undoubtedly that the chief determinant of epidemic malaria is rainfall. It remains for us to see to what extent epidemic malaria is related to rainfall.

I.—The Rainfall of 1908.

According to the Meteorological report the following were the most noticeable features of the weather for this year—

(1) The only marked feature noted in regard to the rains in the early part of the year was an excess of rain in April most marked in the south-east of the Punjab.

(2) The monsoon was not properly established in the Punjab until July, the fall in June being below the average.

(3) The weather in April and May was cooler than usual, but in June the temperature was in excess.

Regarding the Monsoon the following points are drawn attention to—

(1) Owing to the monsoon current being directed to a greater extent than usual to Upper India, the rainfall for the whole monsoon period in the Punjab was very largely in excess.

(2) Unusually heavy rain fell in the western districts in September. In this month rainfall in the eastern districts, especially in the Delhi Division, was in defect.

Total Monsoon Rain.

Map IV shows the monsoon rainfall in 1908 for each recording station in a graphic manner. The chief feature is an area of comparatively heavy rainfall covering the central districts. It will be observed that this latter area corresponds roughly with the northern epidemic area.

The strip of heavy rainfall extending down to Ferozepore and the area of epidemic intensity at Fazilka is significant. The distribution of heavy rainfall over Gujrat and Jhelum is also in keeping with what we know of the distribution of the epidemic.

Gurdaspur, which has curiously enough just missed having a monsoon rainfall of 30 inches, was also passed over by the epidemic. In the meteorological summary it will be seen that whilst in Amritsar the departure from the normal was 15·54 and in Gujrat 18·5, in Gurdaspur it was only 4·94.

The area over Bhera in this year is also an area of heavy precipitation.

Enough has been said to show that in 1908 there was a very close relation between rainfall and epidemic conditions. But we must not be led to the conclusion that the epidemic areas were always those which received the heaviest rainfall. Such an idea can be seen to be inadequate by referring to the figures for Gurgaon and Delhi. According to rainfall Delhi district (34 inches) should have been the most affected, whereas in reality the most affected was Gurgaon (28·9). Or taking another example Sialkot should have been as severely affected as Gujrat.

If we examine the eastern and western edge of the heavy rainfall area (30-inch line) and of the epidemic (epidemic figure over 5), we shall see that whilst epidemic conditions often extend considerably further in a south-west direction than the rainfall would lead us to expect, they very seldom extend at all to the north-east, and are apt in this situation to fail to extend to the rainfall limit.

The only reasonable explanation of this phenomenon is that the effects we see are those of "floods," a conclusion to which further considerations will also take us.

Departure of Rainfall from Normal.

The greatest departure from normal in the total monsoon rainfall was over the district of Montgomery (19·01). Following this are the figures for the district of Gujrat (18·5), Jhang (17·48), Sialkot (16·37) and Ferozepore (16·28). Jhelum and Amritsar show 15·85 and 15·54, respectively. There is thus a relation between the excess over normal and epidemic conditions. But this is by no means absolute. Montgomery behaved in regard to epidemic conditions more in accordance with its total rainfall than with the excess over normal. Sialkot similarly, though it had a high excess over normal, was not seriously affected by the epidemic.

Total Monthly Rainfall and Monthly Excess over Normal Rainfall.

In the case of Amritsar the excess of 15·54 was almost entirely due to rain falling in one month, the total rain in this month (August) being 21·6 inches and the excess being 14·0 inches over the normal. Palwal similarly had 20·85 inches in one month. But Sialkot also received over 20 inches in August without becoming affected, though it is noticeable in this case that, of the excess of 16·37 in the total only 8·72 is made up by the August rainfall, the remainder being distributed over July and September. On the whole if we take those districts which have received over 10 inches excess rain in a single month, we shall in many cases arrive at those which suffered most in the epidemic, but we shall include Ferozepore and only just include Gujrat and generally speaking we are no nearer

the solution of our problem than we were when considering total monsoon rainfall.

Rate and Season of Precipitation.

The monthly rainfall at Amritsar, Palwal, Bhera, Gujrat and Delhi are given in the following table :—

	June.	July.	August.	September.	Total.
Amritsar	0·35	9·70	21·60	3·35	35·00
Palwal	0·92	11·20	20·85	0·65	33·62
Bhera	0·93	5·46	6·41	14·60	27·40
Gujrat	0·26	8·72	17·31	10·57	36·86
Delhi	0·15	14·10	19·85	0·61	34·71

It will be seen that at Palwal and Amritsar the heaviest rain fell in August and at Palwal practically none at all in September. At Bhera and Jhelum the heavy rain was in September, the excess in July and August being slight.

Any very subtle relation to the exact period of the monsoon when excessive rain falls is therefore not probable.

The intervals at which rain fell at a number of places were closely studied, but the only relation which seemed to hold between the character of the rainfall and the epidemic conditions was the heaviness of the falls.

Flooding.

An examination of the recorded rainfall in 1908 monsoon shows us therefore a close connection between the total fall and epidemic conditions. As we proceed to more detail characters the connection is less obvious ; in fact endeavouring to explain the relation of rainfall to epidemic disease, I have arrived after much study at no satisfactory conclusions. But when the rainfall is considered in relation to flooding a great deal of the difficulty disappears.

Ferozepore, we shall see from the table, received a total monsoon rainfall of 27·74 inches and an excess of 16·28 over the normal. We might expect this district to show much higher figures than it has done. The escape of the upper portion of the Sutlej valley in this district is particularly noticeable. But we find that Ludhiana and Jullunder, the districts higher up the riverain, have received only 3·42 and 3·80 excess, respectively. The chief effects are seen lower down the river at Fazilka and Jalalabad where flooding did as a matter of fact occur. The escape of Sialkot is also noticeable and is difficult to explain unless we consider the possibility that for some reason the district was not seriously affected by floods.

II.—Rainfall in previous Years.

In 1908 it will be observed that the line representing the extension westwards of 10 inches monsoon rain is close to the western border of the Punjab and that the area receiving 20 inches of rain and over extends over nearly the whole of the central third of the Province.

1907—1904.

In 1904 the line indicating the extension of 10 inches of rain and over scarcely covers a third of the Punjab, whilst a rainfall of over 20 inches is restricted to a minute portion of the submontane tract. In this year there are no thanas showing epidemic prevalence.

In 1906 the extension of the 10-inch line is about the same, but the 20-inch line includes Sialkot, Gurdaspur, Hoshiapur, Umballa and the districts lying along the Jumna. The districts receiving 30 inches are restricted to parts of Gurdaspur and Umballa. In this year there are a few small spots of epidemic mortality within or just beyond the 30-inch line (Machawara).

In 1905 and 1904 the rainfall is very restricted. No thanas showed epidemic prevalence.

In 1903 the 20-inch line extended in the north as far westwards as the Shahpur district. There were some small epidemic foci, one being at Bhera.

In 1902 rainfall was very restricted and there were no epidemic areas. These years, for the most part conspicuously free from manifestations of epidemic malaria, were therefore also years of small and even deficient rainfall.

1900.

The 10-inch line only includes about half of the Punjab, but the 20-inch line extends nearly as far and the 30-inch line includes Jullunder, Ludhiana and most of Gurdaspur and Hoshiapur. A line representing a fall of 20 inches and over includes Umballa, half of Ludhiana and parts of Hoshiapur and Jullunder. The epidemic of 1900 affected especially the last mentioned districts. Karnal, which was not included but lay just beyond the 30-inch line, was also severely affected. A small area of epidemic is seen in the old bed of the Beas near Kasur.

1894.

There is a marked extension of the 30-inch line which includes Gurdaspur, Amritsar, Jullunder and even parts of Ferozepore, as well as Ludhiana, Umballa, Karnal, etc. The 40-inch line includes Gurdaspur, Hoshiapur and Jullunder. If rainfall alone were concerned, the epidemic should have equalled in area and intensity that of 1900. As a matter of fact the area was small and for the most part of low intensity. Nevertheless it corresponds almost exactly to the area of greatest precipitation.

1892.

In 1892 the 10-inch line includes the greater part of the Punjab, *vide* Map V. The 20-inch line includes Gujrat, Gujranwala, Lahore, half of Ferozepore and all the eastern districts. The area of rainfall receiving 30 inches and over is not extensive; it includes only Gurdaspur, Ludhiana, Umballa and parts of adjoining districts. But the 40-inch line as in 1900 extends to a considerable distance from the hills.

In this year, which it will be remembered is one in which a terrible epidemic involved the northern districts, the rainfall and the epidemic areas seems at first sight to bear no relation to one another. But we notice as in 1908 a great westerly extension of the area of heavy rain along with which we have epidemic conditions in Gujrat and Gujranwala and epidemic malaria of moderate intensity in Shahpur district. Over Gurdaspur also it is possible to account for the malaria by the rainfall. But Sialkot which was severely affected is far to the west of the centre of precipitation.

1890.

I have been unable yet to study the detailed figures for this year, which is the more unfortunate as this, besides being one of the most severe, is the most compact epidemic on record. But very heavy rain fell over Sialkot, Gujrat and Gujranwala, the chief seats of the epidemic.

1884.

In this year most of the Lahore district, Ferozepore and parts of Sirsa received less than 10 inches total monsoon rain. The 20-inch line extended only as far west as Amritsar and Ludhiana. At first sight there is but little relation between the area of heaviest precipitation and the large epidemic area. But scrutiny of the rainfall map shows an area of heavy precipitation further south than usual which, if we take into account flooding, accounts for some of the southern portions of the epidemic. North of Gurdaspur there is another centre of heavy precipitation and associated with it an epidemic area. As in the case of 1892 we can only explain the epidemic nucleus in Luhdiana and over the Sutlej by indirect effects (flooding).

1881.

The great epidemic of Amritsar in 1881 was associated with unusual precipitation over this city.

1879.

There was excessive rain over the southern districts in this year.

From these facts it is clear that epidemics are associated with areas of heavy precipitation and tend not to occur in years of deficient rainfall.

III.—Association of Epidemics with Years of Low and High Rainfall.

In the Appendix are given the monsoon average of twenty-four recording stations in different parts of the plains of the Punjab for a large number of years.

Recollecting what we have learnt regarding the general plan of distribution of rain in the Punjab, these figures can be made use of as a fairly reliable guide to the degree of precipitation and its extension to the west.

Years of Low Rainfall.

Taking first years of low rainfall, we see as we might expect that they are more or less conspicuous as years of low fever mortality.

Years of High Rainfall.

Taking years of high rainfall, we also see a frequent association between years of heavy rainfall and high fever mortality; but in this case it is evident that this relation by no means invariably holds good. In 1875 the rainfall is the heaviest recorded in the Punjab not even excluding the rainfall for 1908. Extremely heavy rain fell also over Gurdaspur and Sialkot. But the epidemic increase in deaths is small. In 1894, another very heavy year, the mortality we have seen was not at all in proportion to the precipitation. In 1884 the rainfall was not abnormally great; nor is there any reason that one can see why 1893 should not have been a fever year as well as 1892, the precipitation being even greater. In 1909 also rainfall was distinctly high, but the year was almost free from epidemic disease. This want of relation is brought out quite as prominently by a study of the figures for different areas and is not due, as one might think, to the average figure employed, giving faulty impression of the conditions.

Years of High Rainfall following Years of Deficient Rainfall.

If, instead of merely looking for an association of high rainfall with epidemics, we take also in consideration the previous year, we find several very striking examples of instances where a deficient rainfall followed by an excessive rainfall is associated with epidemic conditions. The association of this condition with epidemics is made very plain by the series of figures which are obtained by dividing the average rainfall of each year by that for the previous year, the object being of course to bring into proportionate prominence years of heavy rainfall following years of deficient rainfall, *vide* Appendix, col. 5. It will be noted that the process not only picks out most of the epidemic years but in any particular year even approximates in value to the number of deaths from fever. The matter will be further commented upon in a later chapter. For the present we need

only point out that a consideration of rainfall alone does not enable us to pick out fever years with any certainty.

IV.—Temperature.

The variations of temperature recorded for the Punjab show a very regular yearly course. The most marked features are :—

1. The great regularity of the seasonal variations.
2. The drop in the autumn temperature occurring between September and October.

An examination of the records for epidemic and non-epidemic years and for epidemic and non-epidemic *areas* has shown no distinctive features, that are not so far one can see merely the effect of unusually heavy rains.

But there is a way in which variations in temperature may be important. We have seen that rain begins to fall in June and that abundant anopheles are present from July onwards. There seems no reason this being the case why epidemic conditions should start so suddenly with such remarkable rapidity at the time they do. Local conditions seem to have little or no effect in determining the period of onset, and as we have seen the effect is almost simultaneous throughout the Punjab. This onset corresponds very closely with the sudden drop in minimum temperature, and temperature may therefore be an important factor determining the time of onset of an epidemic, other conditions having brought all the necessary factors together for its appearance.

V.—Areas of Epidemic Frequency.

Whatever the cause of epidemics may be, it is very noticeable that for some reason or another they have chosen to fall over some areas more frequently than over others. In Map 11 are shown superimposed the effects of the epidemics we have been studying.

Four distinct areas of special epidemic frequency are clearly seen, a northern area in which the epidemic centres have ranged about Gurdaspur, a central area about Umballa and Ludhiana and a southern area in the neighbourhood of Gurgaon. The fourth type have their centres at or about Jullunder. Omitting 1908, the seven major epidemics have been distributed as follows :—

Three, those of 1876, 1890 and 1892, are northern; three, those of 1878, 1884 and 1900, are central, and one, that of 1879, southern in type.

The most severe epidemic of the fourth type was that of 1878; the mild epidemic of 1894 was over the same area. In 1908 there were two epidemics, one northern and one southern in type.

It will be noted that though the northern area has suffered from epidemics of great area and intensity, it is well to the west of the centre of greatest precipitation. This alone will show the want of exact correlation between rainfall and epidemic malaria. At the same time the dependence of the condition on rainfall is shown by the fact that the northern epidemics occur in years of great westerly extension of precipitation.

The localisation of epidemic conditions to the submontane tracts, which is very clearly shown in Map 11, also shows that a certain rainfall is a necessary factor in the production of epidemic malaria.

CHAPTER XII.

Physical Features in Relation to Epidemic and Endemic Malaria.

I.—Subsoil Water.

Observations at different places visited have shown a marked relation between the level of the subsoil water and malaria. Classified according to the depth of the subsoil water at the different places visited, these may be grouped as follows :—

Time visited.	Village or Town.	Approximate depth of subsoil water in feet.	Spleen rate in percentage.	Epidemic figure in 1908.
April 1909	Palwal	4	85	..
	Janoali	3	100	..
	Dhatir	10	73	..
March 1909 & March 1910.	Amritsar (periphery)	6	90	12
	Atari	9—12	80	5
	Rangahr	8	93	7
	Kahangahr	10	93	..
	Mahawa	5	..	18
March 1910	Gumtala	4	90	12
	Khairabad	10	..	2
August 1909	Bhera	8	83	..
	Miani	6—12	78	..
	Alipur	10	94	30
	Jamat Rangha	8	88	20
	Dhel	9	85	18
	Hafizabad	8	95	18
	Kolian	7	88	41
	Khan Mohamed Wala	5	97	17
	Hathiwind	12	74	..
August 1909	Nabisha	25	67	9
	Bhalwal	38	29	1
	Luliani	over 40	21	2
	Kot Momon	„ 40	0	1
August 1909	Akilshah	15	66	3
	Shahpur	11	48	..
	Nathuwala	8	40	1
	Kandan	4	53	30
	Wegowal	30	68	10
	Dharemia	30	48	..
August 1909	Gujrat centre	27	38	..
	Gujrat margin	8—10	51	..
	Gurali	4	94	46
	Kuthala	3	80	27
	Nurpur	3	52	..
	Nairowali	10	26	2
	Shadiwal	13	42	25

The Relation to Endemic Malaria.

The effect of a high subsoil water upon endemic malaria is not difficult to understand. Whatever the conditions, whether the soil be sandy or impervious, a high subsoil level means the existence of perennial breeding places of anopheles and all the conditions classically associated with this disease.

The existence of considerable malarial infection, when the subsoil water is so low as 40 feet, shows that the relation is only a relative one.

The Relation to Epidemic Malaria.

In this respect we have a more difficult problem. *It is clear that the mere existence of a high subsoil water does not in itself lead to epidemic malaria,* as is evident from the conditions in Amritsar and in the villages of the Amritsar thana in 1909 and 1910, when a high subsoil level was associated with no epidemic increase of mortality.

II.—Porosity of the Soil.

Experiments to ascertain the relative porosity of the soil were undertaken with samples of soil from Palwal, Dhatir, Pirthala, Amritsar and Sheikpura and elsewhere. The method finally used was the following :—

A sample of soil was allowed to dry, and was then roughly broken up and a portion of it passed through a sieve. After mixing the sifted material to ensure a uniform sample 20 grams was weighed out.

This was then placed in 100 cc. of distilled water and shaken in a laboratory-shaker for an hour. It was found that the values given later depended very largely on the amount of shaking. After shaking the sample was poured rapidly into a tube prepared as follows. A straight lamp glass with a bulb at one end is prepared by tying over the straight end a piece of muslin. Into this is tilted 20 cc. of dry washed sand and the tube is placed at rest with the muslin just submerged in a vessel of water. When the sample is ready, it is taken from the shaker, rapidly poured through a funnel into the tube, water being added to fill the tube up to the top. Subsidence takes place rapidly at first but very slowly later, so that in the case of the Punjab soil it often takes several hours for the bulb of the lamp glass to empty itself. So soon as the fluid reaches the lower end of the bulb the time is noted and 50 cc. of water is added. The numbers of hours taken before the level again reaches the bottom of the bulb was then recorded. If the lower end of the tube is not submerged the rate of percolation will be modified by capillarity in connection with the muslin, the method the drop falls and so on; by placing the end of the tube under water this fallacy is done away with.

The chief difficulty to be got over is the great variation which results from different degrees of shaking; and so far this has prevented any really reliable

figures being obtained. But the following observations serve to enlighten us in some respects as to certain factors concerned in water-logging.

Series 1. Sand washed and shaken	. . . 30 seconds	} under 1 minute.
„ „ „	. . . 3 minutes	} in both cases.
Amritsar soil shaken	. . . 30 seconds	40 minutes.
„ „ „	. . . 3 minutes	147 „
„ „ „	. . . 10 „	250 „
„ „ „	. . . 30 „	375 „

Porosity is therefore not only a matter of the original character of the soil but depends upon the effect water has in resorting out its particles. The imperviousness noted in the longer shakings was due to quite a thin layer of very fine mud last deposited from suspension.

Series 2. Mean of a number of observations on soil shaken 30 seconds.

Pirthala soil	(sandy)	25 minutes.
Amritsar soil	(close)	55 „
Palwal soil	(very close)	over 4 hours.

Series 3. Mean of a number of estimations using the method described above with shaking for one hour.

Dhatir soil	(sandy)	4·25 hours.
Pirthala soil	(sandy, but less so than above) .	7 hours.
Palwal soil	. . . . .	11·5 hours.

Even the washings of a soil that are obviously sandy may form therefore a very impervious layer. The very slow percolation under these conditions is very marked.

Capillarity and Gravity.

Series 4.

Palwal soil, an estimation as above	. . . . 660 minutes.
Palwal soil, an estimation as above, but end of tube buried in dry sand instead of being allowed to rest in water	. 35 minutes.

In the former gravity alone is in action. In the latter this is aided by the action of capillarity exerted by the dry sand upon which the tube rests. The action of capillarity under these circumstances in causing percolation is therefore as compared with gravity enormous. Such experiments were repeated under various conditions, in every case yielding results which showed that when dealing with an impervious soil the effect of capillarity was immensely greater in causing percolation than was gravity alone.

Two long tubes, $\frac{1}{2}$ inch diameter, were filled (*a*) with powdered Palwal earth, (*b*) with fine dry sand; both were shaken down as much as possible and the tubes

placed upright, their lower ends resting in a vessel of water. The line of visible wetting rose as follows :—

Palwal Soil	24 hours . .	69 cm.
	48 „ . .	76 „
	96 „ . .	85 „ and still higher later until a fissure in the column interfered with the experiment.
Sand	24 hours . .	40 cm.
	48 „ . .	40 „
	96 „ . .	40 „

There is therefore a great difference between (*a*) sand and (*b*) fine silt as regards the height to which capillarity will carry up moisture. A close grained silty soil is therefore more apt than a sandy area to become water-logged since (*a*) it becomes saturated to a greater height above the subsoil level, (*b*) the closeness of its particles which make it act in this way also make it very impervious to percolation by gravity.

Water-logging.

Summarising these facts we can see that when rain falls two forces are in action causing any collections of water unable to drain off to sink into the soil; these are gravity and capillarity. The relative value of these two forces depends upon the nature of the soil. In loose sandy soil gravity is an important force; in close impervious clay or silt this force acts much less effectively and capillarity is mainly concerned in the disappearance of surface water.

When by saturation of a fine silty soil, like that of the Punjab, the power of exercising capillarity is wholly or in part done away with, rain water sinks in with extreme slowness.

If the subsoil water is at a depth of only a few feet the soil, even to the very surface, has drawn up moisture and having thus lost partially or wholly its power to absorb by capillarity is rendered extremely impervious.

When the subsoil water is on the contrary at a considerable depth, any rain falling on the soil finds it ready to exert its full absorptive power, both gravity and capillarity acting.

When more rain falls surface water is still acted upon by capillarity, because the soil at a given depth is still absorbing water from the upper portions. But if sufficient rain falls in a sufficiently short space of time, there comes about a condition in which either the descending moisture meets with the saturated layer above the subsoil water or owing to the depth of moist surface soil, capillarity cannot act with sufficient speed to effect the surface and again we come to water-logging, but in this case independently of subsoil water altogether.

When water-logging has come about and rain falls, the number of surface pools and the time they retain water is greatly increased. There is also the fact

commented upon in a previous chapter that anopheles larvæ are capable, if a pool dries up, of surviving and continuing their development when more rain falls if they are not exposed to more than a certain amount of desiccation. This time is greatly extended in the case of a water-logged soil.

Water-logging therefore greatly favours the breeding of anopheles and may, when associated with frequent rain showers, possibly bring about an increase in their numbers comparable with the swarming of certain other species of insects. In the absence of rain a water-logged soil, though it allowed a certain number of anopheles to breed, is not necessarily favourable to a great increase of the genus. The comparative importance of such conditions as compared with the formation of extensive *sheets* of water cannot, in the absence of observations in epidemic times, be stated.

III.—The Effects of Irrigation.

Irrigation broadly speaking in the Punjab is of three types—(*a*) well irrigation, (*b*) irrigation inundation canals, and (*c*) irrigation by the great canal systems.

The first we need not consider here as it is presumably the form of irrigation least likely to affect the incidence of malaria. The second type embraces a variety of conditions varying from the small privately-owned nullahs to larger canals resembling the canals of the great systems. The conditions at Wegowal point to the serious effects which flooding from these canals may give rise to. A flooded tract by a canal of this kind was also seen in the Bhera thana, many acres being converted into what seemed to be a semi-permanent swamp. Such canals however exist only over a comparatively insignificant proportion of the Punjab and scarcely concern us in our present effort to arrive at the factors concerned in the great epidemics.

The Great Canal Systems.

Originating from the river Jumna close to where this issues from the hills is the Western Jumna Canal. This canal after running for about 50 miles without many branches breaks up into a net-work of distributaries over the Karnal, Rohtak and Hissar districts. From the Sutlej at Ruper issues the Sirhind Canal which, forming a great loop with its convexity facing south, sends off a net-work of distributaries to supply the western half of Ludhiana, the native state of Patiala and the southern portion of Ferozepore. No other system occurs until the Beas is crossed and the Bari Doab system is reached. There is thus a large tract embracing the whole of Jullunder and Hoshiapur, the eastern half of Ludhiana, and much of the Umballa district which is scarcely touched by any irrigation system properly so called. In Umballa and Hoshiapur however much minor irrigation is carried on.

Beyond the Bari Doab there is again a break in the irrigated area occupying Sialkot and a portion of Gujranwala. Beyond this there is a broad irrigated tract extending as far as the Jhelum.

A moment's consideration will show that epidemic prevalence is in no way due to these great irrigation works. It would almost seem that whilst the irrigated tracts are often comparatively exempt from epidemic influences, parts like Sialkot, eastern Ludhiana and Umballa, which are not irrigated by these systems, suffer especially severely. The real reason of this is of course more or less obvious, the canals irrigating tracts which on account of their natural dryness are comparatively unsuited to epidemic conditions. If any relation exists between irrigation and epidemic prevalence it can only be that irrigation may render a tract more liable than it would normally be to influences bringing about epidemics.

Canals and Subsoil Water.

The Bari Doab and especially the district around Amritsar is frequently cited as an over-irrigated tract. It is also stated that the present condition of high subsoil water level is entirely due to this irrigation continued over many years. Even so, with the exception of Amritsar city, we do not find this district so very liable to severe epidemics and the southern portion of the tract will be seen from the composite map (Map 11) to have been comparatively little affected by epidemic conditions.

Canal Overflows.

If canals are seriously affecting the epidemic incidence in any tract it is very probable that it is due to *overflows*. By this I do not mean small leaks but the formation of extensive sheets of water which in a sense reproduce the conditions suitable for epidemic intensity.

IV.—Epidemic Reaction.

By noting the behaviour of different areas to epidemic conditions we may distinguish the following:—

1. Tracts which although they may not exhibit epidemic conditions for years are in some way so predisposed to them that on a certain minimum of rainfall they will (some other necessary factor which we shall discuss later being present) become the seat of epidemic malaria. It will be quite clear from the maps of epidemic areas in different years that of such a nature are portions of riverains, their behaviour in this respect either causing them to be picked out as areas of slight intensity when at a distance from the epidemic nucleus or as areas of special intensity when within the zone of severe epidemic conditions. Notably among such areas are the Jhelum riverain at Bhera, the Sutlej riverain near Ferozepore, the old bed of the Beas near Kasur, the neighbourhood of Thanda Urmar and so on.

In addition to tracts of this nature there are others which are not obvio. riverain but nevertheless behave in the same way. One such tract lies to the north-west of Lahore (Muridke, Kamoke, etc.,) and was well picked out in the 1908 epidemic. In reality it is a broad low-lying area at the foot, so to speak, of the district of Sialkot so that it receives much of the drainage from this district.

Another type of tract similar to the last mentioned in regard to its behaviour to epidemic disease though not in physical features is that to which Gujrat and the thanas along the foot of the Siwalik hills in Hoshiapur belong.

Such tracts not only easily become affected but exhibit a high degree of epidemic intensity, the death rate generally being during the epidemic months about 400 per mille.

2. Tracts which are possessed of the necessary topographical features but have never or very seldom exhibited an epidemic mortality because they lie beyond the range of the necessary monsoon rainfall. Of such a nature must be large portions of the western Punjab.

3. Tracts which from their physical features are less easily affected by epidemic conditions and in which the death rate is usually less than in waterlogged tracts under similar epidemic conditions. Tracts of this nature when they occur beyond the zone of heaviest rainfall exhibit their relative powers of resistance very strikingly. After passing sufficiently west they are often exempt from epidemic malaria whilst the riverains are still liable to be affected. But the protection afforded by physical features once within the zone of full epidemic influence is comparatively small. There is scarcely any part of the eastern submontane tract which has not at some time or another become part of an epidemic focus. If we search for a tract which within the last forty years has never exhibited a death rate due to epidemic malaria of over 10 times the normal we shall find that over the large area shown in Map 11 not a single thana has escaped. If we similarly look for a thana which has never been subjected to epidemic conditions of a severity represented by the epidemic figure of 7, we shall find the whole of Gujrat, Sialkot, Gurdaspur and Hoshiapur and most of Gujranwala, Amritsar, Ludhiana and Karnal, as well as the whole of the south-eastern extremity of the Punjab, closed to us. In other words, within these areas it is not a matter of the local conditions of particular thanas which is concerned but simply of the areas chosen by epidemics.

A very reasonable presumption, looking at Map 11, is that, given sufficient rainfall, etc., any part of the submontane tract is capable of exhibiting epidemic conditions of the utmost severity.

CHAPTER XIII.

The Human Factor.

The researches of Celli in Italy and of Dr. Bentley and myself in India show the necessity of considering the conditions affecting the human host as well as those affecting the numbers and life generally of the mosquito. In dealing with epidemic conditions associated with high mortality this is especially necessary.

I.—Mortality Incidence among different Classes.

The following table gives the mortality among Mahomedans and Hindus at Amritsar during the epidemic years 1908, 1892, 1881.

	September.		October.		November.	
	M.	H.	M.	H.	M.	H.
1908	62·3	86·6	390·3	203·0	329·4	181·5
1892	123·6	79·9	168·5	122·1	126·4	99·3
1881	348·6	190·0	548·9	318·5	324·8	223·0

The increased rate among the Mahomedans who form the bulk of the poorer classes is very noticeable. The very high rates in 1881 were associated with distress among the same class, largely Kashmiri shawl weavers, etc., who were adversely influenced by decay of the shawl industry.

The most affected parts of the city in 1908 were, we have seen, Khazana and Mahan Singh. Both these sections are noticeable for the large proportion of low class Mahomedans and Kashmiris. So far as one could judge from impressions gained during investigations at Amritsar, it was the Kashmiris who also suffered most severely in 1908.

A feature of the mortality at Amritsar was the large relative proportion of deaths amongst adults as compared with many other places.

At Delhi in the city proper those wards inhabited by the poorest class suffered the most severely. Ward XI, where mortality was greatest, is mainly inhabited by the very poor.

At Palwal the large proportion of the population who were of the lowest social status was very marked, quite large quarters being composed entirely of Chamars and similar low castes. The mortality was also as at Amritsar very great among adults.

Bhera seemed a well-to-do town, though this impression was modified by closer acquaintance. It was noticeable here that the adult death rate was not very high.

Among poor and dependent classes we therefore get a higher mortality than among the well-to-do. How far this is due to the less deadly effects of malaria or to an increased indirect action of the disease it is impossible to say. The proportion of adult deaths would seem to have some significance, but the matter requires further study. The important point is that in arriving at an estimate of the effects of malaria in different towns and villages, it is necessary to recognise and allow for this class coefficient.

II.—Spleen Rate and Social Status.

An analysis of observation upon enlargement of the spleen in Amritsar and Delhi gave the following results :—

AMRITSAR—							
Khatris, Aroras, Brahmans	0	0·9	25·6	19·5	54	46 %	348
Talis, Kamiars Oil-people, potters, etc.	1	7·5	38·1	27·2	26·2	73 %	294
Cultivator Class, including Cow-keepers	4·1	10·9	29·9	25·8	29·9	70·9%	147
Low class Kashmiris and Sweepers	2·5	10·7	40·5	25·1	21·1	78·9%	279
DELHI—							
Brahmans, Banyas, etc.	0	5·0	18·0	17·0	60·0	40·0%	108
Lohars, Dhobies, etc.	0	8·0	36·0	26·0	30·0	70·0%	50
Chamars, Sweepers	9	12·0	49·0	11·0	18·0	82·0%	63

These data are to a considerable extent influenced by the fact that the better class live in more healthy parts of the towns. But in the following rates, which are those for rural areas, this cannot seriously influence the figures :—

PALWAL—							
Brahmans, Banyas	0	13·5	40·6	25·0	20·8	79·2%	96
Cultivators (Rajputs and Jats)	5	18·0	38·4	21·8	16·6	83·4%	78
Telis, Chamars and Sweepers	4	18·2	36·4	13·6	10·0	90·0%	110
ATARI—							
Arains, Lohars, etc.	·2	5·5	38·2	40·0	16·4	83·6%	55
Chamars, Sweepers	·1	12·3	47·7	20·0	10·8	89·2%	65
MIAN MIR—							
Sikhs, Banyas	0	2·0	30·0	26·0	39·0	61·0%	126
Chamars, Sweepers	0	10·0	44·0	24·0	21·0	79·0%	57
SHAHPUR—							
Aroras and Raolis	1	3·0	27·0	14·6	54·2	45·8%	96
Low class cultivators	0	12·3	18·8	24·6	24·0	76·0%	65
GUJRAT—							
Aroras	0	0	5·0	5·0	16·0	38·5%	26
Cultivators	0	7·7	19·6	19·0	53·8	46·2%	117
Lohars, Tarkhans	·2	5·0	11·3	29·5	52·3	47·7%	44
Telis, Mochis and Sweepers	1	4·0	34·3	18·0	41·7	67·0%	67

Among poor and dependent classes we therefore get a higher mortality t. among the well-to-do. How far this is due to the less deadly effects of malaria e. to an increased indirect action of the disease it is impossible to say. The proportion of adult deaths would seem to have some significance, but the matter requires further study. The important point is that in arriving at an estimate of the effects of malaria in different towns and villages, it is necessary to recognise and allow for this class coefficient.

II.—Spleen Rate and Social Status.

An analysis of observation upon enlargement of the spleen in Amritsar and Delhi gave the following results :—

AMRITSAR—							
Khatris, Aroras, Brahmans	0	0·9	25·6	19·5	54	46 %	348
Talis, Kamiars Oil-people, potters, etc.	1	7·5	38·1	27·2	26·2	73 %	294
Cultivator Class, including Cow-keepers	4·1	10·9	29·9	25·8	29·9	70·9%	147
Low class Kashmiris and Sweepers	2·5	10·7	40·5	25·1	21·1	78·9%	279
DELHI—							
Brahmans, Banyas, etc.	0	5·0	18·0	17·0	60·0	40·0%	108
Lohars, Dhobies, etc.	0	8·0	36·0	26·0	30·0	70·0%	50
Chamars, Sweepers	9	12·0	49·0	11·0	18·0	82·0%	63

These data are to a considerable extent influenced by the fact that the better class live in more healthy parts of the towns. But in the following rates, which are those for rural areas, this cannot seriously influence the figures :—

PALWAL—							
Brahmans, Banyas	0	13·5	40·6	25·0	20·8	79·2%	96
Cultivators (Rajputs and Jats)	5	18·0	38·4	21·8	16·6	83·4%	78
Telis, Chamars and Sweepers	4	18·2	36·4	13·6	10·0	90·0%	110
ATARI—							
Arains, Lohars, etc.	·2	5·5	38·2	40·0	16·4	83·6%	55
Chamars, Sweepers	·1	12·3	47·7	20·0	10·8	89·2%	65
MIAN MIR—							
Sikhs, Banyas	0	2·0	30·0	26·0	39·0	61·0%	126
Chamars, Sweepers	0	10·0	44·0	24·0	21·0	79·0%	57
SHAHPUR—							
Aroras and Raolis	1	3·0	27·0	14·6	54·2	45·8%	96
Low class cultivators	0	12·3	18·8	24·6	24·0	76·0%	65
GUJRAT—							
Aroras	0	0	5·0	5·0	16·0	38·5%	26
Cultivators	0	7·7	19·6	19·0	53·8	46·2%	117
Lohars, Tarkhans	·2	5·0	11·3	29·5	52·3	47·7%	44
Telis, Mochis and Sweepers	1	4·0	34·3	18·0	41·7	67·0%	67

These data show clearly the influence of low social status on the spleen rate. They also show the peculiar high rate common among the "cultivator class." This same high rate amongst this class is also seen in the Amritsar figures.

III.—Scarcity.

Though trade, etc., in the Punjab is undergoing considerable expansion and the building of railways and other works is progressively increasing, it is almost certain that this is not directly related to the great epidemic conditions we are discussing.

The distribution of the epidemics shows very clearly that the conditions leading to epidemic malaria were very widespread and had been exerted at intervals as far back as we have records of the Punjab. It is necessary therefore to consider whether there were not influences affecting the general population which may have to be taken into account.

At Amritsar it was clear that there were all the possibilities of an exaggerated human factor. It seems generally acknowledged that among the labouring and artizan classes in Amritsar City, especially among the Kashmiris, the pinch of poverty is severely felt. The latter class especially is apparently living under conditions which favour the continuance of residual infection.[1]

At Palwal and Delhi the presence of poverty turned one's attention to more general conditions which we may sum up under the term "scarcity."

The question of food and diet is too complicated to be discussed adequately in the present report. But it became evident, as the enquiry proceeded, that a full dietary, as understood by the well-fed European, falls to the lot of but few of the poorer classes, and that in times of scarcity these are accustomed to adapt themselves to circumstances *by proportionately restricting the amount of the food they take.* The extent to which this state of affairs seemed to exist was sufficient to show that, if the human factor were at work, it was in the form of a proportionate stress upon the whole population, and that one must look for its most marked effects in years of scarcity.

We have had ample evidence that epidemics are determined by rainfall, and though we cannot predict in any particular year what a heavy rainfall will bring about, it seems certain that a deficient fall is never associated with severe epidemic conditions.

Even if scarcity is in reality involved in epidemic causation, we should not expect to find it acting in the absence of the necessary factor of rainfall. We must not look also for the effect of famine in this respect in the famine districts at the time of the famine, for at this time the essential factor, excess of rainfall, is absent.

---

[1] *Vide* a paper by Christophers and Bentley "The Human Factor," read at the Bombay Medical Congress, 1909.

But if heavy rain were to fall upon a famine-stricken district, we might then reasonably expect this to be followed by severe epidemic conditions.

That the most severe epidemics follow very frequently this sequence, is apparently the general experience of all who have had intimate acquaintance with the Punjab. The following abstract from the Gurgaon Gazetteer gives a graphic account of the 1879 epidemic which followed the famine year of 1878:—

> "In the beginning of the year 1877 the condition of the district as a whole was unusually prosperous. There had been no serious drought for eight years and the harvests had been almost without exception up to or above the average for at least five years. There had been no serious mortality of men or cattle for some years; and in population, extent of cultivation and irrigation, number of cattle and amount of accumulated capital, the district was probably richer than it had ever been before. But the rains of 1877 were very scanty in amount and very inopportune in their distribution; the autumn crop of 1877 was a complete failure and the following spring crop very poor. Four-fifths of the district presented the appearance of a barren desert, and the usual growth of grass and fodder entirely failed. The supply of fodder available was soon consumed, and even the dry thatch of deserted huts was pulled out, and chopped up, and given to the cattle as fodder mixed with the leaves of trees as a last resource for keeping them alive. During the cold weather the cattle died rapidly and in great numbers, and heaps of bones lying round nearly every village attested the great mortality. It was estimated that nearly half of the 300,000 cattle in the district died of starvation in that one year, a loss to the peasantry equivalent to 15 lakhs of rupees or more than a year's land revenue of the district. The scarcity caused by the failure of harvests hardly deepened into actual famine, although there were some deaths from starvation, and a large portion of the population was greatly weakened by want; *but it was followed in 1878 and 1879 by a dreadful epidemic of fever, and in those two years 103,000 persons or more than a seventh of the total population died;* the death rate per thousand per annum was 68 in 1878, and 81 in 1879, and the abnormal mortality of those years was more than 60,000 persons.

The italics are mine.

In regard to an increase of mortality in Hissar in 1897 the Famine Commissioners are quoted in the Census of India, p. 67, as attributing this to fever "of the ordinary malarial type which always occurs when a year of heavy monsoon rainfall succeeds a year of drought," and they add that the number of deaths

" was increased by the enfeeblement of health which a prolonged period of prixation had produced."

In the 1900 epidemic the Famine Commissioners of 1901 found that " much of the mortality was due to an unusually unhealthy autumn acting upon a population predisposed to disease by privation."

In the Punjab severe famines have occurred in 1860-1861, 1868-1869, 1877-1878, 1895-1896 and in 1899-1900.

For the years 1860-1861 there are no records of mortality, in 1868 deaths from fever in October and November were only 31,099, but in the year following the famine 1869 they rose to 116,540 or, considering the registration at that time, a rate characteristic of a first class epidemic. In 1877 deaths in the two months noted above only reached 38,837. In the year following they were 180,356, this being one of the worst epidemics the Punjab has ever suffered from. In October and November 1896 deaths were 73,239, the year following they were 141,573. Following the year 1899 with 69,200 deaths from fever comes 1900 with a total number of deaths in the two months of 254,580.

Each of the four great famine periods for which we have any records was then followed by " fever years." Even if we look at the total deaths from all causes, we shall see that the number of deaths due to the famine was negligible when compared with that due to the fever which followed.

The effect of famine upon the population was therefore not directly the most important cause of death. On the other hand, one may justly surmise that in these instances malaria merely reaped a harvest prepared for it by the famine.

These facts certainly show that there may be a very direct connection between the actual famine or very severe scarcity and epidemics. But we should not be justified in assuming that all epidemic years are of this class. As a matter of fact out of the twelve or so epidemics of which we have records only four can be considered as famine epidemics.

As years have advanced it has become more and more impossible for famines to manifest themselves, and even if several monsoons partially fail it is usually scarcity rather than famine that ensues. But if actual famine may be a precursor of epidemics, we may reasonably expect to be able to trace the effects of the mitigated condition of scarcity. This is however a difficult task, for it is clear we must know something about local as well as general conditions of prosperity or the reverse before we can hope to be very successful, and this knowledge is not very easy to get at.

IV.—Relation of Price of Food Stuffs to Epidemic Conditions.

The most obvious method of getting a general idea of the prevalence of adverse or prosperous conditions at different times is by examining the fluctuations

in the price of the food stuffs. Unfortunately, whilst prices give us a good idea of the degree of general scarcity, they fail to point out to us areas especially affected by failure of corps and other adverse conditions, the reason being that there is a very remarkable averaging process in regard to ruling prices, so that, however severely one area is affected by shortage of crops, the prices after a brief discrepancy tend to level up if the other areas are unaffected. High prices may even increase the prosperity of a tract in which crops have been successful.

With this reservation we may compare the average annual rates of the price of wheat for a number of years with the incidence of fever epidemics.

It will be seen that these annual average prices have risen and fallen in the course of years almost in a rhythmical manner between a rate of about 10 seers to the rupee and a rate as high as 25 seers for the rupee.

Also we cannot help being struck by the fact that if we take the summit of the curve in each case it will be found to coincide with an epidemic. Thus the first curve reached its greatest height in 1869, the second in 1879, the third in 1887, the fourth in 1892, the fifth in 1897, the sixth in 1900 and the seventh in 1908. This sequence carried out with such regularity can scarcely be accidental. Also there is evidently more than mere relation to prices, for that the epidemics should always occur at the culminating point strongly suggests that it occurred when in a period of drought and scarcity a heavy monsoon fell. This would then both cause fever and, by giving good crops, lower the prices.

We have by association with famines and with the actual summit of the curves of prices so far accounted for no less than 7 out of the total of twelve or so major epidemics. Passing along the years and comparing the rises in the death rates from fever with prices, we find that the epidemics of 1870, 1872, 1878, 1879, 1881, 1887, 1890, 1892, 1897, 1900 and 1908 were all during periods of markedly high prices. We see also that some epidemics have occurred in years of very low prices, the years in question being respectively 1875, 1876, 1884, and 1894. 1875 and 1876 will be seen from the rainfall data to have been years of very exceptional rainfall. Whether local hardship also entered into these years or not I have not been able to ascertain.[1]

1884 was also a year of very heavy precipitation in the affected areas, Umballa receiving 44 inches and Jagadri 71 inches of monsoon rain. But though the prices given suggest prosperity, I find the year recorded as one in which the very districts concerned (Umballa) underwent great hardship owing to the failure of crops.

---

[1] It is very strange that though the rainfall in 1875 was extraordinarily heavy the epidemic conditions were slight, whereas in the same area less heavy rain next year caused a severe epidemic. It would be interesting to trace out the actual facts were one able to do so, as, for example, whether floods in 1875 did not damage crops to such an extent as to bring about local scarcity. Whichever way one looks at the matter, the year 1876 is quite unique (*vide* correlations in next section).

The year 1894 we have already commented upon. The rainfall over the affected district was phenomenal. As we have shown the epidemic was not a one.

V.—Correlation of Figures representing Fever Mortality with those for Rainfall and Prices.

The close connection between these three series of figures has led me to work out the values with a view to ascertaining the amount of correlation between each series.

The figures representing fever are the number of deaths in October and November of each year taking the unit as 10,000. Those for rainfall are the averages in inches of the rainfall at 24 stations in the plains. For prices have been taken the number of lbs. at which wheat is selling to the rupee deducted from 60, this being to convert the high rates into the higher figures instead of these being represented as they would otherwise be by the lower figures.

A fourth value is also used, namely the coefficient already mentioned in Chapter XI, as obtained by dividing each year's rainfall average by the average for the previous year.

The actual values used are given in an Appendix.

Working out the coefficients of correlation between the fever series and each of the three other series we get :—

1. Fever with Rainfall—
   - Coefficient of correlation . . . . . ·67
   - Three times probable error . . . . . ·168

2. Fever with Prices—
   - Coefficient of correlation . . . . . ·61
   - Three times probable error . . . . . ·201

3. Fever with coefficient obtained by dividing each year's average rainfall by that of the previous year—
   - Coefficient of correlation . . . . . ·74
   - Three times probable error . . . . . ·144

Correlating fever with various combinations of the other values, it was found that the correlation coefficient could be increased thus :—

4. Fever with Rainfall × Prices—
   - Coefficient of correlation . . . . . ·80
   - Three times probable error . . . . . ·114

5. Fever with Rainfall × Prices × Coefficient—
   - Coefficient of correlation . . . . . ·83
   - Three times probable error . . . . . ·099

6. Fever with Prices × Coefficient—

Coefficient of correlation	·80
Three times probable error	·114

The means and standard deviations for each series of values are given beneath each column in the Appendix.

Plotting out the correlations graphically we get the results shown in Charts 6 and 7.

The following abstractions from these are very significant :—

In the 20 years in which rainfall was below the mean (16·6) the average mortality was	81,000
In the 10 years in which rainfall was between 16·6 and 20 the average mortality was	104,000
In the 9 years in which rainfall was between 20 and 30 the average mortality was	177,000
In regard to Rainfall × Prices	
In the 25 years below the mean (40·2) the average mortality was	83,000
In the 10 years between 40·2 and 60 the average mortality was .	121,000
In the 5 years over 60 the average mortality was . . .	217,000

In Chart 6 whilst the epidemic years are seen to follow the correlation line, a very interesting group of non-epidemic years characterised by heavy rainfall are seen markedly diverging from this. The group illustrates very clearly the fact that heaviness of the rainfall is not the only factor at work. It is significant that all these years are years of low prices.

VI.—General Determining Causes of Epidemics.

There seems very little doubt that the two factors, rainfall and scarcity, are the determining causes of the epidemic malaria seen in the Punjab. Broadly speaking until plague appeared malaria must have been the main agent which brought to a head in actual mortality the effects produced by the great economic stresses. Just as in famines malaria cannot act until nature is about to bring them to an end, so there can be little doubt that the effects of scarcity are to a large extent held over until the appearance of the first heavy monsoon. Then though the effect of the rain is to reap a harvest of deaths the period of stress is brought to an end.

The enormous proportion of deaths among infants and the aged in the epidemic mortality has already been referred to. The result of the almost cyclical influences we have indicated upon the population is a curious one and is expressed in the following abstract from the Census of India, which, though it refers to the effects of famine, applies equally to those of epidemic malaria :—

> " All sections of the population however, are not equally affected ; the very old and the very young suffer most, while those in the prime of life sustain only a comparatively small diminution in the numbers . .

> . . Consequently at the close of a famine the population consists of an unsusally small proportion of children and old persons and a large proportion of persons in the prime of life, *i.e.*, at the reproductive ages. For some years therefore in the absence of any fresh calamity the growth of the population is very rapid . . . . . This more rapid growth continues for some years, but then as the persons who at the time of the famine were in their prime pass into old age and their place is taken by the generation born shortly before the famine with its numbers greatly reduced by the mortality which then occurred, the birth rate falls not only below that of years following the famine but also below the average, and the pendulum continues its swing backwards and forwards between periods of high and low birth rate, but its oscillations gradually become fainter until they cease from natural causes to be apparent or, as more often happens, until some fresh calamity obliterates them."

That at the back of such colcssal manifestaticns as the epidemic of 1908 there should be profound and not easily averted natural influences at work is scarcely to be wondered at. When we approach the question of prophylaxis, we shall do well to bear in mind the magnitude of the influences against which we are pitting ourselves and not be led in a foolish vein to reduce the remedy of the whole matter to trifling proportions.

PART IV.

EXPERIMENTAL WORK ON THE MECHANISM OF FULMINANT MALARIA.

CHAPTER XIV.

The Nature of Intense Malaria.

In all that has gone before we assume that malaria has, during the epidemic period, been present in a more intense form than usual. But we have not defined intensity nor considered what such a term implies.

Spleen Rate.

The results of recording the size of 3,134 spleens in children in one or other of the five classes we have hitherto used in recording spleen rate are as follows :—

58	278	1,035	713	1,032

Omitting the last class or those that were negative and recording graphically in percentages we get the result shown in Chart 8 and the following values :—

2·7	13·2	49·2	34·8

Whether we take the rates as ascertained in the examination of 1,256 children in Amritsar or the figures for 1,695 children examined elsewhere in the Punjab, we get a very similar curve as shown by the two series of figures :—

Amritsar	2·4	11·7	48·3	37·4
Elsewhere	2·9	14·1	49·8	33·0

If we take the rate for Hakiman Katra, where the spleen rate works out at 91·6 per cent., we get the variation shown in the figure, and if we work out the rates for an area in the central part of the town we get a variation in an opposite direction, also shown in the figure.

Grouping together those observations which showed an approximately similar spleen rate, we get the following associated variations in the number of spleens in the different classes :—

Amritsar.

Spleen rate 90 per cent. or over	5·1	16·2	46·8	31·7
„ „ 80 „ under 90 per cent. . .	1·7	13·7	53·3	31·1
„ „ 70 „ „ 80 „ . . .	1·3	9·1	54·9	34·5
„ „ 50 „ „ 70 „ . . .	·7	9·2	48·2	41·8
„ „ 30 „ „ 50 „ . . .		2·0	20·4	77·7
„ „ under 30 „ . . .			31·2	68·8

Similarly treating the figures for rural area we get the results as follows :—

Various rural areas.

Spleen rate 100 per cent.	10·4	29·5	44·8	16·4
„ „ 80 „ under 100 per cent. . .	3·1	15·5	54·8	26·4
„ „ 60 „ „ 80 „ . . .	2·1	12·2	54·8	30·8
„ „ 40 „ „ 60 „ . . .	·7	3·5	53·2	42·5
„ „ under 40	1·5	3·0	40·9	54·5

Some approximation of the curves above given is so general that exceptions have only been found when one was dealing with a mixture of two communities. In this case the values at once warned one that conditions were unusual.

With an increase in the number of persons showing evidence of malaria infection there is always under the conditions in the Punjab an increased intensity as shown by the size of the organ.

Parasite Rate.

If in a similar manner we record the parasite finds in 599 blood examinations of children giving as values the number of parasites found in 100 microscope fields, we get the result shown in Chart 9 and numerically recorded below :—

Parasite finds in 599 children

Under 1 per 100 fields, *i.e.*, negative to standard employed 373		
Under 5 per 100 fields	92	40 per cent.
Over 5 but under 10 per 100 fields	48	25 „
„ 10 „ „ 20 „ „ „	39	17 „
„ 20 „ „ 50 „ „ „	32	14 „
„ 50 „ „ 100 „ „ „	10	4 „
„ 100 „ „ 200 „ „ „	3	1 „
„ 200 „ „ 500 „ „ „	1	·4 „
„ 500 „ „ 1,000 „ „ „	1	·4 „

Comparing this curve with that shown by the distribution of parasite values found in the blood of children at Palwal, we see a progression towards the higher values in a very regular way.

We may suspect that intensity of malaria is partly at any rate dependent upon the numerical prevalence of parasites.

Relation of Spleen Rate and Parasite Rate to Epidemic Conditions.

We ha een that the spleen rate of Amritsar and Delhi and elsewhere in the Punjab is normally so high as to approach 100 per cent. Parasite infection is also found in a large proportion of the children. These conditions are not in themselves necessarily associated with the excessive mortality of epidemic times. But from what we have said in the last section it would be possible nevertheless that the epidemics were associated with an increase of the numerically higher infections.

In figures already given in the section upon Amritsar it will be seen that the autumn increase in spleens and parasites was of this nature, and that the condition in February 1909 was as regards parasites and spleen rate more intense than even at the height of the fever season of 1909. The high parasite rate at Palwal shortly after the epidemic is also remarkable and is probably not normal. A remarkable feature in regard to spleen rate and parasite rate demonstrated by Charts 10 and 11 is the relative stability of the curves which are not apparently easily displaced to any degree.

CHAPTER XV.

Experiments upon the Quantitative Factor in the Transmission of Proteosoma to Sparrows by the Bites of Culex.

When commenting upon the possibilities in connection with the causation of malarial epidemics Colonel Leslie, I.M.S., suggested to me that the effect of the number of bites by infected anopheles might be found to cause differences in the resulting infection and in the incubation period. I had already thought over the considerations outlined in the first chapter of this section and I saw much to favour the view that "intensity" in malaria might be a quantitative matter and that it might depend upon the number of infected anopheles by which the members of a community were being bitten.

Among other facts I called to mind the severe infections that one often sees following even a single night's exposure under circumstances in which one has every reason for believing that infected anopheles abound and the comparative mildness of attacks seen in those who live under conditions in which infected anopheles are comparatively infrequent. That intensity of an attack of malaria might be the result of dosage of infection would also explain the peculiar fact that a person immune to a certain degree of malaria frequently succumbs if he be exposed to a greater intensity of the same disease.

If true this conception would also go far to explaining the occurrence of epidemic conditions and the apparently increased virulence or intensity of the disease at these times.

The difficulties of experimenting on the human subject are great and I determined therefore to obtain such data as I could from observations upon Proteosoma in sparrows, the material for which is unlimited.

The experiments recorded below were carried out by feeding bred *Culex fatigans* upon infected birds and later noting the effect of bites of these upon healthy birds. The sparrows when brought to the laboratory were at once examined and infected ones placed aside. Those found free from infection were, prior to being utilised for experiment, quarantined for a period of at least twelve days. Before being used their blood was again carefully examined for proteosoma. During the period of quarantine they were carefully protected from the bites of culex in a series of large mosquito nets, only two mosquitoes (neither of which contained sporozoites in the glands) being found throughout the course of the experiments to have gained admission to these birds.

In the experiments only mosquitoes which in the morning were seen to contain blood were noted as having fed. Birds which had been enclosed with mosquitoes

which had apparently not fed were liberated as it was not possible to be sure they had not been bitten.

After the experiment as before the birds were most carefully protected from stray mosquitoes.

I—Experiments to show the Effect of the Bite of a Single Infected Mosquito.

Experiment 1.

21st May 1909.—Batch 1 mosquitoes fed on Sparrow 17 in whose blood were a fair number of proteosoma.
24th May 1909.—A mosquito dissected showed fairly numerous zygotes present.
28th May 1909.—Sparrow 32 fed on by a single mosquito of this batch.
2nd June 1909 and 3rd June 1909.—Examined daily. Blood negative.
4th June 1909.—2 parasites per 100 fields.
5th June 1909.—2 parasites per 100 fields.
6th June 1909.—Blood negative.
8th June 1909.—1 parasite per 100 fields.
Incubation period—7 days.
Infection—very mild.

Experiment 2.

22nd May 1909.—Batch 2 mosquitoes fed on Sparrow 19 in whose blood were numerous proteosoma.
26th May 1909.—1 mosquito dissected showed numerous zygotes (in places as many as 5 per field) in the gut.
30th May 1909.—Sparrow 52 fed on by a single mosquito of this batch. Mosquito dissected showed sporozoites.
31st May 1909 to 4th June 1909.—Examined daily. Blood negative.
5th June 1909.—A single proteosoma parasite seen after long search.
6th June 1909.—2 parasites per 100 fields.
7th June 1909.—2 parasites per 100 fields.
8th June 1909.—Negative.
11th June 1909—Negative.
Incubation period—6 days.
Infection—mild.

Experiment 3.

1st June 1909.—Sparrow 47 fed on by a single mosquito of Batch 2. A mosquito dissected on this day showed numerous sporozoites in the glands.
2nd June 1909 to 7th June 1909.—Examined daily. Blood negative.
8th June 1909.—10 parasites in 100 fields.
9th June 1909.—55 parasites in 100 fields.
10th June 1909.—100 parasites in 100 fields. Numerous segmenting forms. Bird quiet.
Incubation period—7 days.
Infection—medium.

Experiment 4.

31st May 1909.—Batch 5 mosquitoes fed on Sparrow 19.
3rd June 1909.—A mosquito dissected showed a moderate number of zygotes.
10th June 1909.—Sparrow 158 fed on by a single mosquito from this batch. A mosquito dissected showed not very numerous sporozoites in the glands.
11th June 1909 to 16th June 1909.—Examined daily. Blood negative.
17th June 1909.—5 parasites per 100 fields.
18th June 1909.—2 parasites per 100 fields.
20th June 1909.—2 parasites per 100 fields.
22nd June 1909.—Negative.
24th June 1909.—Negative.
Incubation period—7 days.
Infection—mild and evanescent.

Experiment 5.

8th June 1909.—Sparrow 156 bitten by a single mosquito of Batch 5. This mosquito dissected showed a fair number of sporozoites in the glands.
12th June 1909 to 26th June 1909.—Examined daily. Blood negative.
Result—negative.

Experiment 6.

10th June 1909.—Sparrow 159 fed on by one mosquito of Batch 5. Mosquito dissected showed scanty sporozoites.
15th June 1909 to 26th June 1909.—Examined daily. Blood negative.
Result—negative.

Experiment 7.

11th June 1909.—Sparrow 169 fed on by 2 mosquitoes of Batch 5. These mosquitoes dissected showed in both cases scanty sporozoites in the glands.
15th June 1909 to 19th June 1909.—Examined daily. Blood negative.
20th June 1909.—1 parasite per 100 fields.
21st June 1909.—8 parasites per 100 fields.
22nd June 1909.—28 parasites per 100 fields.
23rd June 1909.—2 parasites per 100 fields.
25th June 1909.—Negative.
28th June 1909.—2 parasites per 100 fields.
Incubation period—9 days.
Infection—mild.

Experiment 8.

30th May 1909.—Batch 7 mosquitoes fed on Sparrow 23, whose blood contained numerous proteosoma.
6th June 1909.—A mosquito dissected showed numerous sporozoites in glands.
7th June 1909.—Sparrow 110 fed on by one mosquito of above batch.
12th June 1909 and 13th June 1909.—Examined daily. Blood negative.
14th June 1909.—16 parasites per 100 fields.

16th June 1909.—80 parasites per 100 fields.
16th June 1909.—240 parasites per 100 fields.
20th June 1909.—370 parasites per 100 fields.
22nd June 1909.—Bird dead. Proteosoma in heart's blood, 400 per 100 fields segmenting forms.
Incubation period—7 days.
Infection—mortal.

Experiment 9.

18th June 1909.—Batch 12 mosquitoes fed on Sparrow 179 whose blood contained numerous proteosoma.
27th June 1909.—Sparrow 184 fed on by a single mosquito from Batch 12. Dissected showed abundant sporozoites in glands.
3rd June 1909.—Blood negative.
4th June 1909.—5 parasites per 100 fields.
5th June 1909.—25 parasites per 100 fields.
Bird accidently killed.
Incubation period—7 days.
Infection—

II.—Experiments to show the Effect of a Number of Bites by Scantily Infected Mosquitoes.

Experiment 10.

28th May 1909.—Batch 3 mosquitoes fed on Sparrow 31.
31st May 1909.—Mosquitoes found to have only a few zygotes. Every mosquito examined however was infected.
31st May 1909.—Sparrow 54 bitten by 6 mosquitoes of Batch 3.
1st June 1909 to 8th June 1909.—Examined daily. Blood negative.
9th June 1909.—4 parasites per 100 fields.
10th June 1909.—2 parasites per 100 fields.
11th June 1909.—2 parasites per 100 fields.
Incubation period—9 days.
Infection—mild.

Experiment 11.

2nd June 1909.—Sparrow 57 fed on by 12 mosquitoes of Batch 3.
3rd June to 7th June 1909.—Examined daily. Blood negative.
8th June 1909.—16 parasites per 100 fields.
9th June 1909.—8 parasites per 100 fields.
10th June 1909.—8 parasites per 100 fields.
14th June 1909.—4 parasites per 100 fields.
17th June 1909.—Negative.
Incubation period—6 days.
Infection—mild.

Experiment 12.

4th June 1909.—Sparrow 58 fed on by 5 mosquitoes of Batch 3.
5th June 1909.—Sparrow 58 fed on by another 5 mosquitoes of Batch 3.
6th June 1909.—Sparrow 58 fed on by another mosquito of Batch 3.
7th June 1909.—Sparrow 58 fed on by two mosquitoes of Batch 3.
Two mosquitoes were dissected showing in both cases very scanty sporozoites.
8th June and 9th June 1909.—Examined daily. Blood negative.
10th June 1909.—2 parasites per 100 fields.
11th June to 14th June 1909.—Examined daily. Blood negative.
15th June 1909.—2 parasites per 100 fields.
Incubation period – 6 days.
Infection—extremely mild.

Experiment 13.

10th June 1909.—Batch 9 mosquitoes fed on Sparrow 108.
18th June 1909.—Sparrow 177 fed on by 8 mosquitoes of above batch. Dissected, five showed very scanty sporozoites and three were negative.
22nd June to 28th June 1909.—Examined daily. Blood negative.
Result—negative.

III.—Experiments to show the Effect of a Number of Heavily Infected Mosquitoes.

Experiment 14.

30th May 1909.—Sparrow 43 bitten by 10 mosquitoes of Batch 2.
31st May 1909.—Sparrow 43 bitten by 5 more of same batch.
31st May 1909.—Mosquito dissected after feeding on sparrow, glands swollen with sporozoites.
31st May to 3rd June 1909.—Examined daily. Blood negative.
4th June 1909.—30 parasites per 100 fields.
5th June 1909.—170 parasites per 100 fields.
6th June 1909.—340 parasites per 100 fields.
7th June 1909.—290 parasites per 100 fields.
Bird ill, blood very anæmic.
9th June 1909.—170 parasites per 100 fields.
Bird not so ill.
25th June 1909.—600 parasites per 100 fields.
Bird moribund. Flagellating forms present.
Incubation period—5 days.
Infection—mortal.

Experiment 15.

14th June 1909.—Batch 11 mosquitoes fed on Sparrow 43.
21st June 1909.—Sparrow 180 fed on by 8 mosquitoes of Batch 11.
Mosquitoes dissected showed 2 with abundant sporozoites.
4 with fairly abundant sporozoites.
2 with scanty sporozoites.

26th June 1909.—8 parasites per 100 fields.
27th June 1909.—40 parasites per 100 fields.
28th June 1909.—125 parasites per 100 fields.
29th June 1909.—480 parasites per 100 fields ; bird seedy.
2nd July 1909.—Bird died.
Incubation period—5 days.
Infection—mortal.

Experiment 16.

13th June 1909.—Batch 10 mosquitoes fed on Sparrow 43 which was a very heavily infected experimental bird (*vide* Exp. 14).
22nd June 1909.—Sparrow 45 fed on by 6 mosquitoes of Batch 10.
These dissected showed (1) mosquito with enormous numbers of sporozoites in glands. (2) very abundant sporozoites. (3) abundant sporozoites.
26th June 1909.—2 parasites per 100 fields.
27th June 1909.—105 parasites per 100 fields.
28th June 1909.—320 parasites per 100 fields.
29th June 1909.—130 parasites per 100 fields.
30th June 1909.—140 parasites per 100 fields.
3rd July 1909.—1,220 parasites per 100 fields.
7th July 1909.—Bird died.
Incubation period—4 days.
Infection—mortal.

Experiment 17.

14th June 1909.—Sparrow 173 fed on by 3 mosquitoes of Batch 14.
These dissected showed (1) abundant sporozoites in glands (Series A). (2) scanty sporozoites in glands (Series A). (3) scanty sporozoites in glands (Series A).
15th June to 21st June 1909.—Examined daily. Blood negative.
22nd June 1900.—2 parasites per 100 fields.
23rd June 1909.—20 parasites per 100 fields.
24th June 1909.—2 parasites per 100 fields.
25th June 1909.—2 parasites per 100 fields.
Bird recovered.
Incubation period—8 days.
Infection—mild.

Experiment 18.

18th June 1909.—Batch 13 mosquitoes fed on Sparrow 23 whose blood showed numerous proteosoma.
27th June 1909.—Sparrow 181 fed on by 3 mosquitoes from Batch 13.
These dissected showed (1) abundant sporozoites in glands. (2) scanty sporozoites in glands.
30th June and 1st July 1909.—Examined daily. Blood negative.

3rd July 1909.—1 parasite per 100 fields.
4th July 1909.—12 parasites per 100 fields.
5th July 1909.—88 parasites per 100 fields.
6th July 1909.—64 parasites per 100 fields.
7th July 1909.—75 parasites per 100 fields.
Bird recovered.
Incubation period—6 days.
Infection—medium.

IV.—Experiments to show Effects of Bites by Infected Mosquitoes upon Birds already Infected.

Experiment 19.

30th May 1909.—Sparrow 39 fed on by 4 mosquitoes of Batch 2.
2nd June 1909.—5 parasites per 100 fields.
3rd June 1909.—1 parasite per 100 fields.
4th June 1909.—1 parasite per 100 fields.
5th June 1909.—Negative.
8th June 1909.—40 parasities per 100 fields. Bird seedy and anæmic.
9th June 1909.—32 parasites per 100 fields.
10th June 1909.—8 parasites per 100 fields.
14th June 1909.—12 parasites per 100 fields.
Bird recovered.
Incubation period—(?)
Infection—probably superadded to original mild infection which had probably been overlooked.

Experiment 20.

20th June 1909.—Sparrow 177 scanty proteosoma.
25th June 1909.—Sparrow 177 proteosoma 2 per 100 fields.
26th June 1909.—Sparrow 177 fed on by 5 mosquitoes of Batch 13.
28th June 1909.—3 parasites per 100 fields.
30th June 1909.—5 parasites per 100 fields.
3rd July 1909.—34 parasites per 100 fields.
4th July 1909.—28 parasites per 100 fields.
5th July 1909.—100 parasites per 100 fields.
Bird escaped.
Incubation period— (?)
Infection—superadded.

In the course of these experiments a number of points have presented themselves. When commencing the experiments I had thought only of the "number" of infected mosquitoes concerned. But it is obvious that there is another matter to be considered.

A mosquito (culex) fed on a sparrow whose blood contains only a few gametes of proteosoma, shows in the mid-gut only a few zygotes, and in mosquitoes so fed

when the zygotes have matured and the sporozoites have reached the salivary glands, only a very few of the salivary cells are packed with sporozoites; it is evident that such a mosquito feeding on a bird will inject at the most a comparatively small number of sporozoites.

Some of the experiments suggest that in this case one may use large numbers of mosquitoes without producing much result. But in mosquitoes fed on a bird whose blood contains very numerous gametes, the mid-gut is studded with hundreds of zygotes and when the sporozoites have reached the glands these become swollen with innumerable multitudes of sporozoites. Such a mosquito must inject a dose perhaps a hundred times greater than one of the slightly infected mosquitoes we have referred to.

Using scantily infected mosquitoes even in great numbers it is difficult to get a severe infection; single heavily infected mosquitoes on the other hand often give quite severe infections. But by using a number of heavily infected mosquitoes not only was the incubation period reduced from nine days to as little as five days, but the resulting infections were much more severe and death in every case occurred.

The last two experiments show that when a bird already having parasites in its blood is bitten by heavily infected mosquitoes it still developed a new infection over and above the old one.

The amount of infection carried by mosquitoes then depends on the number of zygotes which develop in the gut, and the number of these in turn depends upon the number of gametes in the blood of the sparrow by which the mosquito has become infected.

It is easy therefore to see that in malaria everything may depend upon the existence of heavy gamete carriers; and if these are present upon the number of anopheles: otherwise the relation of number of anopheles to the amount of fever will not hold good.

PART V.

Summary of Conclusions.

Briefly recapitulating the facts recorded in the earlier parts of the paper we can summarise the results of our observations as follows :—

(1) Malaria in the Punjab is manifested in two ways, namely as "endemic malaria" and as "autumnal epidemic" or "fulminant malaria."

(2) Economically the latter is by far the most important and it is the effects of this form which are usually referred to when the disastrous results of malaria in the Punjab are spoken of.

(3) The epidemic of 1908 was of this character and there have been similar and almost if not quite as severe epidemics at intervals at least as far back as the sixties.

(4) These epidemics are focal, that is, their effects are greatest in the centre of the epidemic area and fade towards the periphery. Their distribution vividly calls to mind such phenomena as areas of low or high barometric pressure and not at all that of a disease following lines of communication or even local peculiarities of the ground.

(5) The history of past epidemics shows that they affect all parts of the submontane tract but have shown a special frequency over certain areas. In 1908 there existed for the first time two distinct major epidemic areas, the southern one producing epidemic effects also over the western half of the United Provinces.

(6) Epidemic malaria attacks most severely those communities which already show a high degree of endemic malaria. It is therefore not merely the result of malaria attacking those unaccustomed to the disease nor are endemic areas in any way protected against it.

(7) The most salient feature of the epidemic condition is the excessive mortality and its conspicuously infantile character.

(8) The condition of a population in the Punjab as regards natural increase or decrease is influenced rather by the number and severity of the epidemics to which it has been exposed than by its endemic malaria. Even the effects of famine are mainly shown through the effects of the epidemic malaria which follows them.

(9) Town and cities suffer equally with, even in some cases more than, rural areas, and even the centre of the large cities, Amritsar and Delhi, are only moderately protected from epidemic effects.

(10) The determining causes of epidemics are excessive rainfall and scarcity ; the former is an essential whilst the latter is an almost equally powerful influencing factor. Owing to the meteorological cycles there is a

a population already infected and that what happens in the fever season is the "hastening up" of this infection.

(14) Experiments on sparrows and proteosoma show that severity of infection is largely dependent on the dose inoculated. This is not merely a matter of the number of infected mosquitoes but of the number of sporozoites injected at each bite. This in turn depends upon the number of gametes in the blood of the original sparrow by which the mosquito was infected. Under experimental conditions the latter was the most important factor and it was easy to see as a result of dissection that one heavily infected mosquito might inject more sporozoites than a hundred that were only scantily infected.

No observations exist as to the conditions in regard to anopheles at epidemic times, but the close association of fulminant malaria with actual flooding suggests something more than the ordinary reproduction of the genus in pools, etc. The matter is the most urgent still awaiting elucidation.

(15) Physical features influence epidemics and low water-logged areas are especially susceptible to epidemic conditions. Higher tracts, on the contrary, are comparatively less susceptible. But these differences are often lost when a district becomes involved in the nucleus of an epidemic area.

(16) The great canal systems have no distinct influence upon malaria of this kind, though it is possible that neglected canal irrigation with extensive local floodings may have had very serious effects in the past.

PART VI.

Conclusions on the Chief Methods to be Advised in the Prophylaxis of Malaria in the Punjab.

An elaborate discussion as to the methods of prophylaxis in malaria would be out of place in the present work. It is necessary only to call attention to the more important considerations called forth as a result of the present investigation.

The subject of prophylaxis among Troops, Jails and European communities is also outside the scope of the present report which has dealt throughout with the fundamental conditions as shown by malaria of the native population.

Rural Areas.

Endemic Malaria in Rural Areas.—A high degree of malaria is a common character of almost all rural populations in the Punjab. Even the healthiest villages show rates which in contrast with those quoted for Egypt must be considered high. This amount of infection is not always associated with a very obvious proportionate prevalence of anopheles and even when closely investigated is found to depend to a large extent upon conditions in regard to the anopheles factor whose chief character is their temporary and even fleeting nature. It thus happens that villages and towns are most frequently seen under conditions which, if they were to continue uninterruptedly, would probably be associated with much reduced prevalence of malaria. In all operations directed against malaria in villages we have to bear this in mind, nor is it in the present day sufficient to locate a few sources of anopheles to explain the existence or the degree of malaria. If in a malarious village there are only a few sources of anopheles at the time of some particular visit the probability of there being an enormous number at some other time of the year is very great. For a reduction of this endemic malaria we require a greater and more detailed knowledge of the conditions influencing it both as regards any measures in the nature of drainage (other than the drainage we shall refer to later of special nature) or of quinine prophylaxis.

It is not at all certain which are the most important sources of anopheles in many rural areas, whether pits and excavations are in themselves largely or only in a minor way concerned, and the whole matter is too uncertain for specific recommendations yet to be made. Also this aspect of the matter is less urgent than that which we have next to consider.

Fulminant Malaria in Rural Areas.—The terrible effects of an epidemic are greatly in excess of anything that results from the normal endemic conditions. And even though the death rate is raised by endemic malaria, the effect of epidemic conditions is vastly larger and more important. Of the effects of epidemics

we may distinguish various degrees. The effects of the first degree are such as caused consternation at Amritsar and such as anyone visiting the villages can see was equally exhibited over the country. My own impression supported by facts already given in the descriptions of epidemic areas is that this high degree of epidemic intensity is almost if not entirely a matter of villages being flooded. What the action of the flood waters may be, does not at present concern us. If there are no flooded villages in a thana the total death rate will at most only be moderately increased. In the controlling of floods we have then one very clear objective and one which is within some measure of possible attainment.

The controlling of floods must often be a matter of drainage, but such drainage must not be confused with drainage of the soil which, though it may often be affected in the same way, is a much larger question. In Gujrat flooding is largely a matter of overflow of rivers and here extensive bunds are called for and their construction has in some cases been carried out.

The beneficial results likely to follow immediate removal or prevention of flood water are so great that there seems little doubt that in the Punjab *this should be the first step in the sanitation of a rural tract*, especially tracts known to suffer from the effects of such conditions.

Drainage in the sense of a system of surface drains or of subsoil drainage is a matter we need not now enter upon. Under the circumstances present in India it can only be carried out in a limited manner. If we seek to avert epidemic malaria by such means we have 50,000 square miles to treat before we have the zone of epidemics under control.

It is more important to point out that the facts regarding the influence of subsoil water and the conditions relating generally to the occurrence of the second and third degree of epidemic intensity are still very imperfectly known.

Measures of a detailed anti-larval nature are not indicated and as in Mian Mir they probably would not serve to protect the inhabitants in the very year in which this would be necessary.

If as seems to be the case severe epidemic malaria follows flooding, the most energetic anti-mosquito campaign can influence but little the vast mortality which may occur in any year in almost any district. That under these circumstances, until drainage can be instituted, the use of quinine as a prophylatic and as a means of saving the life of actual sufferers must be pushed to the utmost, is self-evident.

Small Towns of the Punjab.

Nothing can be more striking than the way these towns, often extremely compact and apparently unlikely to be affected by malaria, have been penetrated to their centre by epidemic conditions. It is extremely doubtful if the origin of these conditions is to be found within the actual limits of the town and any

scheme to prevent the disastrous effects of epidemics must be prepared to take into count at least the immediate surroundings. Very often as at Bhera these surroundings strike one as not being very easily controlled, but it is probable if hydraulic measures were considered as of prime importance a good deal might be done. Here as in the rural areas the urgency of quinine organisation cannot be exaggerated.

Cities of the Punjab.

The conditions at Amritsar were so severe that the desirability of protecting so important a city is very evident.

Amritsar is already drained in a fashion and the question arises as to what are the various degrees of drainage we may employ. The crux of the whole question lies in the fact that as a rule those places which it would be comparatively easy to drain are drained and are not malarious, whilst such places as Amritsar impose great obstacles to proper drainage. The slope of the Punjab in this region is about 1 foot per mile. To find a vent efficiently to carry off flood water from the great depressions around the city of Amritsar, must mean a main drain at least some 20 miles in length. To fill in a small fraction of the land (197 acres) around the city took 8 years (1884—1892) and cost Rs. 2,56,568; the filling in of the depressions would therefore be a very great undertaking.

Within the city boundaries on the west there are areas of waste land and excavations which could be drained with an efficient outfall, but which could scarcely be dealt with without this provision. There are also public and private gardens to be considered.

Conditions around the immediate periphery of the city as regards the breeding of anopheles could be greatly improved. There are also many parts within the city that could be rendered safe as regards the breeding of anopheles, at a moderate cost. Intramural measures would probably increase the protection of the more central portions and perhaps narrow the peripheral zone of high intensity. The important point is to combat the conditions that are apt to arise in very heavy rain; otherwise efforts are likely to be stultified by as severe an epidemic as ever making its appearance.

At Delhi closure of the large disused wells should be a measure to be undertaken at once, but apart from this a great deal has still to be worked out before really responsible recommendations could possibly be given.

In conclusion, I wish to acknowledge the great assistance I have received throughout from my laboratory staff, especially from Hospital Assistant Khazan Chand to whose untiry energy and zeal I am largely indebted for much tedious work connected with abstracting mortality and rainfall figures and whose assistance in Amritsar City and in the villages has been invaluable.

Year.	Fever deaths in ten thousands.	Rainfall.	Prices.	Coefficient.	Rainfall × Coefficient.	Prices × Coefficient.	Rainfall × Prices.	Rainfall × Prices × Coefficient.
1868	3·11	10·7	25	1·0	10·7	25·0	26·75	26·75
1869	11·65	18·1	32	1·6	29·0	51·2	57·92	92·67
1870	8·05	15·6	28	0·9	14·0	25·2	43·68	39·31
1871	3·82	14·2	16	0·9	12·8	14·4	22·72	20·45
1872	8·24	22·0	20	1·6	35·2	32·0	44·00	70·40
1873	5·81	18·1	16	0·8	14·5	12·8	28·96	23·17
1874	4·42	16·9	12	0·9	15·2	10·8	20·28	18·25
1875	8·45	27·7	10	1·6	44·3	16·0	27·70	44·32
1876	17·42	17·2	10	0·6	10·3	6·0	17·20	10·32
1877	3·98	8·5	14	0·5	4·2	7·0	11·90	5·95
1878	18·04	18·5	30	2·2	40·7	66·0	55·50	122·10
1879	14·20	16·6	34	0·9	14·9	30·6	56·44	50·80
1880	6·81	15·3	32	0·9	13·8	28·8	48·96	44·06
1881	10·61	18·6	24	1·3	24·2	31·2	44·64	58·03
1882	9·36	19·0	18	1·0	19·0	18·0	36·20	36·20
1883	6·12	12·8	16	0·7	9·0	11·2	20·48	14·34
1884								
1885	8·16	14·3	10	1·0	14·0	10·0	14·30	14·30
1886	6·68	18·2	19	1·3	23·7	24·7	34·58	44·95
1887	13·66	20·6	32	1·2	24·7	38·4	65·92	79·10
1888	9·37	17·3	30	0·8	13·8	24·0	51·90	41·52
1889	11·91	14·9	20	0·9	13·4	18·0	29·80	26·82
1890	23·46	20·7	26	1·4	29·0	36·4	53·82	75·35
1891	8·45	12·3	30	0·6	7·4	18·0	36·90	22·14
1892	27·32	23·0	33	1·9	43·7	62·7	75·90	144·21
1893	8·45	23·7	24	1·0	23·7	24·0	56·88	56·88
1894	14·28	23·1	10	1·0	23·1	10·0	23·10	23·10

Year.	Fever deaths in ten thousands.	Rainfall.	Prices.	Coefficient.	Rainfall × Coefficient.	Prices × Coefficient.	Rainfall × Prices.	Rainfall × Prices × Coefficient.
1895	7·32	15·9	20	0·7	11·1	14·0	31·80	22·26
1896	6·57	11·2	33	0·7	7·8	23·0	36·96	25·8
1897	14·16	14·7	35	1·4	20·6	49·0	51·45	72·03
1898	8·69	13·8	28	0·9	12·4	25·2	38·64	34·78
1899	6·92	7·5	20	0·5	3·7	10·0	15·00	7·50
1900	25·46	21·7	35	3·1	67·3	108·5	75·95	235·44
1901	14·42	12·5	30	0·5	6·2	15·0	37·50	18·75
1902	9·30	15·2	26	1·2	18·2	31·2	39·52	47·42
1903	13·53	16·5	15	1·1	18·1	16·5	24·75	27·22
1904	7·03	10·1	10	0·6	6·1	6·0	10·10	6·06
1905	6·11	10·1	15	1·1	12·0	16·5	16·35	17·98
1906	11·51	19·9	35	1·7	32·5	59·5	66·85	113·64
1907	8·04	11·6	40	0·6	7·0	24·0	46·40	27·84
1908	30·73	26·3	42	2·2	57·9	92·4	110·46	243·01
Mean	11·04	16·6	24	1·07	20·2	28·6	40·2	52·63
Standard deviation . .	6·3	4·6	9	0·54	14·2	22·3	20·6	52·58

CALCUTTA
SUPERINTENDENT GOVERNMENT PRINTING, INDIA
8, HASTINGS STREET