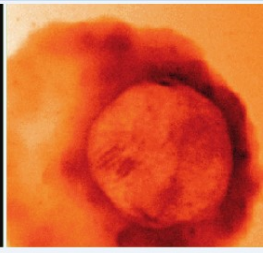
ADVANCES IN ASIAN HUMAN-ENVIRONMENTAL RESEARCH



R. Akhtar · A. K. Dutt · V. Wadhwa (Eds.)

Malaria

Eradication and Resurgence During the Second Half of the Twentieth Century

Malaria in South Asia

Advances in Asian Human-Environmental Research

Aims and Scope

The series aims at fostering the discussion on the complex relationships between physical landscapes, natural resources, and their modification by human land use in various environments of Asia. It is widely acknowledged that human-environment-interactions become increasingly important in area studies and development research, taking into account regional differences as well as bio-physical, socio-economic and cultural particularities.

The book series seeks to explore theoretic and conceptual reflection on dynamic human-environment systems applying advanced methodology and innovative research perspectives. The main themes of the series cover urban and rural landscapes in Asia. Examples include topics such as land and forest degradation, glaciers in Asia, mountain environments, dams in Asia, medical geography, vulnerability and mitigation strategies, natural hazards and risk management concepts, environmental change, impacts studies and consequences for local communities. The relevant themes of the series are mainly focused on geographical research perspectives of area studies, however there is scope for interdisciplinary contributions.

For further volumes:
http://www.springer.com/series/8560

Malaria in South Asia

Eradication and Resurgence During the Second Half of the Twentieth Century

Edited by

Rais Akhtar

Jawaharlal Nehru University, New Delhi, India

Ashok K. Dutt

University of Akron, OH, USA

Vandana Wadhwa

Boston University, MA, USA

Springer

Editors
Dr. Rais Akhtar
Jawaharlal Nehru University
Centre for the Study of
Regional Development
New Delhi-110067
India
raisakhtar@hotmail.com

Dr. Ashok K. Dutt
University of Akron
Dept. of Geography and Planning
Akron OH 44325-5005
USA
dutt@uakron.edu

Dr. Vandana Wadhwa
Boston University
Dept. of Geography and Environment
675 Commonwealth Ave.
Boston MA 02215-1401
USA
vandanaw@comcast.net

ISBN 978-90-481-3357-4 e-ISBN 978-90-481-3358-1
DOI 10.1007/978-90-481-3358-1
Springer Dordrecht Heidelberg London New York

Library of Congress Control Number: 2009938705

Cover Images: Background - Situation in Bihar, India after the November 2008 flood. Such situations arise on a regular basis in many parts of South Asia, where the water is not flushed away for a long period of time. The combination of stagnant water and vegetation makes for ideal mosquito breeding grounds. Copyright © Aleema Shivji/Handicap International (used with permission). Images from left to right: Buckingham Canal on the east end of central Chennai, India (Photo credit: A.K. Dutt); Mosquito, *Anopheles stephensi* in flight (Photo credit: Hugh Sturrock, Wellcome Images, http://medphoto.wellcome.ac.uk/); Malaria Parasite (the *P. falciparum*) in a human red blood cell imaged with XM-1 soft x-ray microscope (Photo credit: (Late) Werner Meyer-Ilse and Cathy McGowan, http://www.cxro.lbl.gov/BL612/ALS_Abstracts_97/ALS_Abstract_Werner97b.html).

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Foreword

Malaria is one of the most widespread and devastating infectious diseases in the world. More than half the world population residing in over 100 countries is at risk of infection from this vector-borne disease. An estimated 250–500 million malarial cases occur each year, resulting in nearly one million deaths, the overwhelming majority of which are children. Because of the magnitude of the associated fatalities, development experts consider malaria a 'silent tsunami,' comparing its death toll to the Indian Ocean tsunami (IOT) that ravaged several countries of South and Southeast Asia on December 26, 2004. That tsunami killed some 300,000 people (including children) at once. Globally, malarial deaths account for about 9% of all childhood deaths each year. However, with malaria more than most fatal diseases, mortality is a small fraction of morbidity. Malaria is a debilitating disease, particularly for the adult population.

In addition to children, pregnant women and migrating populations are most vulnerable to malaria. Miscarriage, stillbirth, and low birth weight are common among pregnant women who are infected with this disease. Malaria manifests itself through recurrent fever and chills, with associated symptoms such as anemia and an enlarged spleen. If a person survives the disease, he or she will develop a certain degree of immunity for some years. But malaria victims are not only deprived of energy, they also face an increased risk of other diseases taking hold in the weakened body.

Malaria also has economic implications at the household and national level. To many development experts, the economic retardation of tropical countries, where most of the world's poor live, can be substantially explained by the prevalence of malaria.

Malaria is preventable and curable, but it is not possible to completely eliminate malaria without development of an effective vaccine, for which there are not even any medium-term prospects. Therefore, people all over the world, particularly those in the tropical countries, must be informed about the habitat of its vectors, chain of disease transmission, spatial and temporal distribution of the disease, and strategies to control and reduce the incidence of malaria through interrupting the transmission cycle and by other means. Providing this and other relevant information, this book aids those who have inadequate understanding of this infectious disease. Most publications on malaria focus exclusively on sub-Saharan Africa, yet this book is appropriately devoted to a world region where, in absolute terms, many

more people are at risk of contracting malaria than the highly endemic region of sub-Saharan Africa. The large population of South Asia translates into higher risk for more people.

Additionally, South Asia has witnessed numerous changes over the last few decades through rapid urbanization, domestic and intra-regional migration, and expansion of irrigated land as a result of the adoption and diffusion of green revolution technology in the countries of this region. Many development projects, such as the construction of dams and embankments to control abnormal floods, have started in recent decades. All these have led to an expansion of breeding environments for the malaria-carrying *Anopheles* mosquito. This has ultimately resulted in the resurgence of malaria in South Asia via growing resistance in the mosquito vector to pesticides, such as *dichlorodiphenyltrichloroethane* (DDT), and the *plasmodium's* resistance to most major antimalarial drugs. Moreover, islands and coastal countries of South Asia are most vulnerable to global climate change, which will likely increase the breeding habitat of most mosquito vectors.

Sri Lanka, the largest island nation in South Asia, was one of the first countries in the world to formally launch a massive attack on the mosquito with the use of DDT in the 1940s – earlier than the World Health Organization (WHO) sponsored Malaria Eradication Program (MEP). Aiming to interrupt transmission using the known intervention points, the WHO launched its malaria eradication campaigns in 1955. After realizing that it was not possible to eradicate malaria in 1992, the WHO renamed the MEP, the Malaria Control Program (MCP).

Sri Lanka was also one of the first countries to experience great success in the war against malaria. As a result of its eradication program, the mosquito was practically wiped out of Sri Lanka within a short period of time and the rate of death attributable to malaria fell markedly. The death rate fell from 22 per 1,000 live births in 1945 to 8 in 1972 and to 5 in 2004. Although malaria continues to be present in Sri Lanka, today only a few people die from this disease and its malaria morbidity rate is also one of the lowest among malaria-prone countries of the world.

Following Sri Lanka's initial success, India, Bangladesh, and Pakistan initiated a massive assault against the mosquito, and the number of new cases of malaria dropped dramatically. But soon the mosquito developed resistance to DDT and malaria resurgence occurred in most South Asian countries. South Asian countries suffer severely from this disease, and the threat of malaria remains constant. This is reflected in the fact that anti-malarial activities started in this region much earlier than in other malaria-prone regions of the tropics and still continue today.

Over the years, in keeping with the continuously changing requirements for malaria control due to the constantly shifting nature of vector, agent, physical, and economic environments, the WHO has responded with modified strategies of its own. When the multi-partner 1998 Roll Back Malaria Initiative did not have the desired impact despite all the right approaches, mainly due to the lack of coherent leadership, the WHO took responsibility for all current worldwide malaria control and elimination efforts under the umbrella of its comprehensive Global Malaria Program.

By concentrating on South Asia where malaria has a long history and requires continuous monitoring and control, the editors of this volume have selected a study area which has rarely received attention from malaria researchers. For this reason, the editors of this volume deserve credit and appreciation for exposing the risk of malaria that this world region faces to the other malaria researchers, health administrators, public health personnel, nongovernmental organizations (NGOs), donor agencies, and the general public. All of them, particularly policy makers, will find this volume highly useful because it points out the shortcomings of malaria control programs undertaken so far in South Asia and elsewhere, as well as outlines how to improve these programs to decrease the incidence of malaria all over the world, thereby reducing the suffering of millions. They will also gain understanding regarding the cycle of malaria occurrence in South Asian countries, diffusion of malaria and paths of malaria transmission within and beyond the countries of the region, and spatial patterns and causes of resurgence, including post-resurgence characteristics, subsequent control, and preventive measures introduced. This understanding is essential to combat and eradicate malaria.

The editors of this volume are among the most prominent and authoritative experts in malaria research. Professor Ashok Dutt and Professor Rais Akhtar have conducted such research for their entire academic careers, which have lasted for more than three decades to date. They are pioneers in geographical and social science research on malaria in general, particularly in the South Asian context. More than 30 years ago, when I came to North America for advanced studies, I read their papers on malaria as class readings. Dr. Vandana Wadhwa is a young and dedicated scholar of medical geography already publishing in major journals, who has a very high potential to become one of the leaders in the field of malaria research in the near future.

The contributors of this volume are also drawn from the most qualified researchers in this field. Dr. Hiran Dutta and Dr. K. Maudood Elahi have made notable contributions to malaria that are familiar to many. Many of the other contributors have extensive academic experience, as well as field knowledge of malaria-related research, and I have great respect for their work. I am honored and extremely fortunate to have been asked to write this foreword for this insightful, valuable, and useful volume. I congratulate the editors and contributors for presenting us this seminal book, and I invite all of you who have interest to learn more about malaria in general, and in South Asia in particular, to read this outstanding book.

Dr. Bimal Kanti Paul
Professor, Department of Geography
Director, South Asia Center
Kansas State University
Manhattan, KS 66506
USA

Preface 1

Of all the tropical vector-borne diseases, malaria is at once both the most important and the one whose reputation has varied most dramatically: for some years it rated as the disease of greatest importance to the World Health Organization; for over a decade after that it could scarcely be mentioned in their offices! Now again malaria is center stage, both as the object of highly productive research and as the target of increasingly ambitious control programs: even the formerly taboo word 'eradication' is being re-discussed. If the world is to go down this path again, then the current generation needs to learn from history and to avoid repeating the errors of the 1960s.

This book can greatly assist the assessment of that difficult period. It casts a less familiar light on the topic, from the viewpoint of medical geography rather than that of medicine, public health, or epidemiology. The authors critically examine the 'post-eradication' era with an emphasis on the spatio-temporal analysis of reported data. They cast new light particularly upon urban malaria due to *Anopheles stephensi,* the spatial patterns of unstable malaria in Sri Lanka, and the analysis of control processes in Pakistan. Their interests and emphases differ from those of malariologists and encourage us thereby to think in new ways, as will be essential if our efforts at control and elimination of malaria are to be more durable in the future than they have been in the past. I therefore welcome this book for its discussions and insights into a great burden upon and threat to the people of South Asia: every public health worker will find something new and of interest in its pages.

Dr. David Bradley
Ross Professor of Tropical Medicine (Emeritus)
London School of Hygiene and Tropical Medicine
London, UK

Preface 2

In the introductory chapter, the editors summarize in one sentence the result of actions taken and observations gathered in one entire century since the discovery, around 1900, of the *Plasmodium* species and their transmission to man by *anopheline* mosquitoes: "By 1995, malaria had become one of the main infectious diseases of the world with mortalities ranging from 1.5 to 2.7 millions persons worldwide." This statement reflects the deep frustration regarding the malaria situation in the South Asian countries after the illusion of eradication created by the WHO-sponsored Malaria Eradication Program carried out with great effort in each of the considered countries in the 1950s and 1960s.

The book, put together by Profs Rais Akhtar, Ashok K. Dutt, and Vandana Wadhwa describes in detail the evolution of the intensity of malaria in the second half of twentieth century in India and in neighboring countries (Sri Lanka, Nepal, Bangladesh, and Pakistan, plus Maldives and Bhutan) regrouped by the editors as "South Asian Region." This evolution is made of cycles of occurrence, near eradication, resurgence (from mild to epidemic), and subsequent questionable control and/or prevention.

Every aspect of the "game between two players, nature and human kind," in other words the competition between the transmission force of the parasite–vector–human host team versus the health task force selecting and carrying out control techniques is exposed with great clarity in the different situations encountered in each particular country of the region.

In the presentation of the transmission force, the complexity is underlined: landscape peculiarities and human activities; immune resistance or susceptibility of the population; vector species efficacy; rural or urban type of environment and habitat; and, last but not least, ongoing climate changes.

The control techniques include: vector control through environment sanitation or insecticides, with special mention of excessive use or ban of DDT; parasite control with anti-malarial drugs; efficiency of health workers; health system coverage; adequate financing and international cooperation.

The result is a plea for cooperation between countries of the region: "South Asia is under one umbrella... a regional approach is not only desirable, but also mandatory," and for the prompt use of scientific breakthroughs regarding treatments and prophylaxes, immune protection of the human host (vaccine, so far a myth),

and genetically acquired refractoriness of mosquitoes against specific *Plasmodium* parasite stages.

The book ends with the presentation of the "Roll Back Malaria" Initiative and the Global Malaria Program that bring new hope by promoting the use in the field of such conclusive advances as given above at the onset of the twenty-first century.

Professor (retd.) Dr. Marc Wéry
Institute of Tropical Medicine
Antwerp, Belgium

Preface 3

> Where malaria prospers most, human societies have prospered least. The global distribution of per-capita gross domestic product shows a striking correlation between malaria and poverty, and malaria-endemic countries also have lower rates of economic growth. There are multiple channels by which malaria impedes development, including effects on fertility, population growth, saving and investment, worker productivity, absenteeism, premature mortality and medical costs (Sachs and Malaney 2002, p. 680)

South Asia, with its warm and humid climate and alternating wet and dry seasons is well suited for malaria, which has virulently attacked its inhabitants for millennia, and unleashed itself even on conquering armies, well-intentioned missionaries, traders, and tourists through the region's long history. This book traces the occurrence of this disease in South Asian countries in more recent history, analyzing the occurrence of malarial episodes during the second half of the twentieth century.

Historically, anti-malaria activity occurred extensively in the twentieth century, jump-started by Alphonse Laveran's from the discovery of the malaria parasite in 1884. This was buttressed by Ronald Ross' discovery of the mosquito as the mode of malaria transmission in 1897–98 through various experiments he conducted in the cities of Secunderabad, India, and in the major South Asian city of Kolkata, which was also the capital of the Raj. Since then, South Asia became a field area for malaria study and malaria prevention activity during the British Regime in the twentieth century. The British Railway and administrative apparatus, which was improved upon after independence of the South Asian countries in the mid-century, provided a perfect network for the World Health Organization (WHO) for its malaria control activities, the immediate effects of which were very evident in India, Sri Lanka, Bangladesh, and Pakistan. Therefore, South Asia is a very valid testing ground for examining the efficacy of malaria-control activities.

At the end of the Second World War, malaria was still a major killer in South Asia. The efforts of the World Health Organization and respective governments of South Asia caused the disease incidence to decline drastically in the 1950s and 1960s. It was thought that malaria was eradicated. By the end of the 1960s and the middle of 1970s the disease began to resurface rapidly all over the sub-continent. This episode of resurgence demanded renewed preventive and curative efforts by the various governments and the World Health Organization. The pace of resurgence was slowed down by these efforts. Nonetheless, the problems and challenges

associated with the post-resurgence phase remained crucial. It is therefore necessary to understand why the disease was brought to an "eradication point" and then resurfaced in the form of resurgence. The post-resurgence period experience is of special interest to medical geographers, epidemiologists, and development planners.

In this book, the authors have tried to assess the historical progression, decline, and resurgence of malaria, using five countries as case studies: India, Pakistan, Bangladesh, Nepal, and Sri Lanka. This is the first book of its kind that provides a geographical study and diffusion analysis of malaria during the recent history of the South Asian countries. We believe that such an examination of the "comeback" of malaria in the recent past will help in fostering a better understanding of the working of the disease, the lapses in judgment and human error that led to such resurgence, and the physical and socio-cultural environments that continue to help the agent and the transmitter of this deadly disease to thrive.

The authors in this book are primarily geographers, and have examined the occurrence of this disease in a geographical, spatial framework. However, the book is intended for an interdisciplinary audience: health and medical geographers, South Asia area studies scholars, epidemiologists, health planners, diffusion analysts, and those interested in disease geoecology and public health. The market for this book also extends to libraries, medical historians, and malaria-control entities at the international, national, state, and local levels. In this volume, indigenous South Asian minds have collaborated with Western and Western-trained scholars in order to portray a scientific analysis of disease occurrence and recurrence.

In the end, the book is a significant regional synthesis of malaria studies that use varied approaches, theoretical groundings, and methods to understand the return of malaria to a region that had almost been at the brink of its eradication. Additionally, we were not satisfied with leaving the reader at the end of the twentieth century—this book addresses more recent developments not only in spatial trends of malaria occurrence, but also in the various medical, public health, and other approaches being used to combat it.

Also addressed is the very crucial element of climate change that is a current concern and challenge. With climate conditions changing due to increased concentrations of carbon dioxide in the atmosphere, conditions for pests also change. The primary malaria agent, the *falciparum* malaria parasite will be able to spread into new areas as is happening in India. Based on the HadleyCM2 climate prediction model's "high" scenario, many areas in the world will come in the grip of *Plasmodium falciparum* by 2050, while other areas will become free of this parasite. Regardless, climate change, including the variations caused by the El Nino-Southern Oscillation (ENSO) will inexorably affect the spatial and temporal trends of malaria occurrence over the coming decades.

Nevertheless, the importance of non-climatic factors, including socio-economic development, immunity, and drug resistance in determining infection and infection outcomes cannot be ignored, particularly in a region like South Asia that is vulnerable on these fronts. However, despite the large populations of South Asia that are at risk to malaria, the region is often overshadowed by the plight of Africa. The authors hope to highlight the malaria situation in the South Asian region so that past

experience may serve as a beacon to the right path forward in this constant war of humanity against this single-celled monster.

Editors

Reference

Sachs, J., and Malaney, P. (2002). The Economic and Social Burden of Malaria. *Nature*, 415: 680–685. Retrieved on May 22, 2009 from Roll Back Malaria website http://www.rollbackmalaria.org/cmc_upload/0/000/015/330/415680a_r.pdf

Acknowledgments

In the process of writing, editing and preparing this volume, there have been many people who have helped and supported us with their skills, thoughtful evaluations, time and good wishes. It is to all those individuals, some of whom we will not be able to name in this short space, but who know who they are, that we extend our heartfelt thanks.

We are grateful to Margaret Gieb who passed away recently. She was Staff Cartographer at the Department of Geography and Planning at the University of Akron, Ohio, and helped prepare and reformat a large number of maps and diagrams included in the book. A number of Graduate Assistants from the Department of Geography and Planning of the University of Akron have helped in typing and formatting the chapters, and preparing the computer-generated maps. They include Dr. Christian Tettey, Dr. Sudhir Thakur, Dr. Rajiv Thakur, Dr. Rajrani Kalra, James Carney, Zenat Hasan, Bilkus Banu, Barbara Prince, and Carmen Silva. The most notable help in formatting and organization of the book has been given by Joseph Boateng, Masters student from the University of Akron.

We are also thankful to scholars such as Dr. Andrew Learmonth, Dr. Bimal Paul, and Dr. Allen G. Noble for commenting on some of the papers presented at various conferences. Their comments brought about significant improvement in the final drafting of the chapters. Dr. Bimal Paul is to be specially thanked for providing the foreword, which adds greatly to the book with its comprehensive summarization, thoughtful evaluation, and gracious commentary. Special thanks also to Dr. David Bradley, Dr. Marc Wery, Dr. Kris Ebi, Dr. Yola Verhasselt, and Dr. Alistair Woodward for their incisive and kind reviews. The input from these luminaries has greatly enhanced the book. We would also like to thank all the authors for their thoughtful contributions that have made the book possible, and in many cases, their valuable ideas and additions that have enhanced it considerably.

We acknowledge the professionalism and help provided by various agencies who have allowed us to use copyright material for this book. These are: Ashgate Publishing Ltd., Aldershot, Hants, England for the permission to use a modified form of the chapter "Health Planning and the Resurgence of Malaria in Urban India" by Rais Akhtar, Ashok Dutt, and Vandana Wadhwa, in Allen Noble, Frank Costa Ashok Dutt and Robert Kent (eds.), Regional Development and Planning for the 21st Century: New Priorities, New Philosophies (1998); Center for X-Ray

Optics, University of California, Berkeley, and Dr. Eric Anderson and Dr. David Attwood (photo credit Dr. Werner Meyer-Ilse and Dr. Cathy McGowan); Handicap International and representative Laethicia Lamotte (photo credit Aleema Shivji); The Hindu editorial administration, Chennai, Tamil Nadu and Mr. Thyagarajan (photo credit P. Goutham), and; Wellcome Trust, London and representative Stella Calvert-Smith (photo credits Hugh Sturrock).

Additionally, I (Rais Akhtar) thank my family, wife Nilofar, and daughter Shirin, who encouraged and sustained me in developing the structure of the book and in editing tasks, and I am deeply grateful for their support and indulgence.

I (Ashok Dutt) would like to thank my wife, daughters, and granddaughters for their constant love and support throughout the long days of writing and editing this book. My special thanks to my wife, Hiran, who on many occasions, including in this instance, has very ably played the additional role of my co-author.

I (Vandana Wadhwa) would like to thank Dr. Ashok Dutt for his immense support and mentorship throughout this whole process, and Dr. Rais Akhtar for his cooperation and guidance. My deepest gratitude goes to my husband, Sree Vikram Bhikkaji, who has been the constant rock by my side, forever supporting my every venture. My sister and inspiration Meenakshi Wadhwa, and my close friends and family deserve sincere thanks for patiently coping with my constant whining. Meenakshi Kumari gets special thanks for plying me with much-needed ‘chai’ on a regular basis to keep me going.

Finally, and perhaps most importantly, we are also deeply indebted to Springer and our entire publishing team, without whose patience, immense competence and support this book would not have come to fruition. We would specially like to thank the dynamic Dr. Robert Doe, who ensured that this book would indeed translate to reality. The incredibly capable and talented Mrs. Nina Bennink deserves very special thanks for her endless patience, expert guidance, and valuable suggestions. Ms. Anandhi Bashyam has borne the brunt of many back-and-forth emails and our relative technological ignorance, but remained patient and provided very capable direction. For this, she deserves great thanks.

We could not complete the journey without you all!

Sincerely

New Delhi, India — Rais Akhtar

Akron, OH, USA — Ashok K. Dutt

Boston, MA, USA — Vandana Wadhwa

Contents

Annotated Glossary and Abbreviations

ACT Artemisinin-based combination therapy. Various antimalarial drugs have been used for curative and prophylactic purposes over time, but most have been rendered only marginally effective due to parasite resistance to them. Artemisinin is still largely effective and is therefore the preferred anti-malarial drug of choice. It is used in combination with other drugs, rather than in monotherapy, to maximize the chances of keeping the resistance phenomenon at bay; thus, the term "artemisinin-based combination therapy"

AMC Anti-Malaria Campaign (Sri Lanka). It was started in 1948 using strategies recommended by the World Health Organization (WHO) sponsored Malaria Eradication Program until 1963, when it was believed that malaria had been eradicated. Anti-malaria activities had to be resumed in a concerted manner in the 1970s once it was established that malaria incidence had begun to resurge.

Anthropophilic In reference to malaria, this applies to vectors that prefer to feed on human blood rather than on other animals such as cattle

API Annual parasite index. Calculated by dividing malaria positive blood samples in an area by the population of the area in thousands.

ASAQ Artesunate-amodiaquine. A combination of two potent anti-malarial drugs currently used as a combination drug to discourage parasite resistance to single drug therapy and also favored for its simple drug regime and relatively cheap access.

Anopheles One of the over 3,500 species of mosquitoes, of which the genus '*Anopheles*' numbers a little over 400. Only 30–40 of these cause malaria, and only the female of this species is responsible for malaria transmission. It was implicated in malaria transmission in 1897 by Ronald Ross.

Bandh Embankments (Bangladesh). Areas between embankments that can collect water after rain, providing areas suitable for vector breeding.

Bils* and *Haors Marshy areas (Bangladesh), typically suitable for vector breeding.

BHC Benzene hexachloride, or more accurately, *Hexachlorobenzene*, is an organochloride used as pesticide, including for killing *Anopheles* and their larvae.

It was used in South Asia as an alternative to DDT, but has not protracted a reaction. It is one of the Persistent Organic Pollutants (POPs) on the list of the Stockholm Convention on POPs. In terms of chemical structure, it is more accurately referred to as HCH. See POPs, Stockholm Convention on POPs, HCH, DDT.

CDC Centers for Disease Control and Prevention (USA). It is the nation's premiere health agency responsible for surveillance, research, and dissemination on public health issues among other tasks.

Chena Traditional Sri Lankan cultivation technique where sections of the monsoon forest are burnt on an ongoing basis to bring them under cultivation for a short time. It has been shown to promote malarious conditions.

DDT Dichlorodiphenyl-trichloroethane. An organochloride first synthesized in 1874, and discovered to have potent insecticidal properties in 1939. It became the miracle insecticide for the developed and developing world alike in the early twentieth century, particularly in the fight against malaria. Used extensively for public health and agricultural purposes, it contributed toward malaria eradication in the West, but also had an adverse environmental impact, leading to its ban from the developed world in the 1970s and calls to do the same in the rest. Its extensive use partly contributed to DDT resistance seen in the *Anopheles* and caused resurgence in many areas of the world due to this phenomenon. While its use has been highly restricted all over the world, its limited use for public health is still allowed, as it remains a powerful insect irritant. It is currently one of the top chemicals on the list of the Stockholm Convention on POPs (see below). Also see POPs and IRS.

Dieldrin A chlorinated hydrocarbon used as a pesticide formulated as an alternative to DDT, but is also on the list of the Stockholm Convention on POPs (see below). It is closely related to Aldrin, its precursor in metabolic stage. It works as a pesticide by causing contact and ingestion (stomach) toxicity in insects.

EDPT Early Diagnosis and Prompt Treatment. A strategy for better malaria control espoused by the WHO and other supranational advisory and funding agencies, such as World Bank and UNDP and their beneficieries.

EMCP Enhanced Malaria Control Program (India). Launched in 1997 with the aid of World Bank, the program identified 19 main cities/towns in 10 Indian states severely affected by malaria to be specifically targeted for anti-malaria drives.

EMVI European Malaria Vaccine Initiative was founded in 1998 by the European Commission to fund and carry out research and trials for a malaria vaccine.

Endophagic In reference to malaria, it indicates the preference of malaria vectors to feed indoors.

ENSO El Nino-Southern Oscillation. A weather phenomenon characterized by unusually warm ocean temperatures in the Equatorial Pacific, consequently affecting usual climate patterns across the globe. Lately, it has been found to have greater anomalous effects due to the effect of the last few decades of global

warming. Research shows that it has altered climatic conditions of many parts of South America and South Asia, thus expanding or restricting malaria occurrence patterns in these areas.

Exophagic In reference to malaria, it indicates the preference of malaria vectors to feed outdoors.

Falciparum The most dangerous of the four malaria-causing parasites causes the greatest number of deaths, neurological disabilities, and often lifelong debilitation. This danger is exacerbated by its continuous adaptation and mutation which often renders it resistant to anti-malarial drugs. See *Plasmodium*

GAVI WHO Global Alliance for Vaccines and Immunizations. An international partnership of various stakeholders under the aegis of the WHO, seeking to fund and carry out research and trials for a malaria vaccine.

GMP Global Malaria Program. A comprehensive program to control and eliminate malaria in areas still affected by it. Since the previous multilateral and multi-stakeholder partnership (Roll Back Malaria) suffered from several flaws including lack of a cohesive leadership structure and clear communication channels, it was found necessary to address these and other concerns, resulting in a worldwide program with WHO as the main nodal agency. It was launched in 2006. Also see RBM and WHO.

HapMap A database indexing the human genetic makeup. Researchers feel that in conjunction with the knowledge of the genome sequence of the vector and the agent, which were decoded by the earlier part of this decade, there is a better possibility of formulating cure and control options that can address matters of vector and *Plasmodium* resistance.

HCH Hexachlorocyclohexane, an organochlorine compound used as insecticide for mosquito control in South Asia. It is also incriminated as a POP and is essentially the same compound as BHC. Resultantly, it is one of the chemicals on the primary list of the Stockholm Convention on POPs (see below). Also see BHC and POP.

IEC Information, education and communication. These aspects are regarded as the three pillars of raising community awareness regarding public health or other social issues. The United Nations Organization and related agencies regard it as an essential tool in combating malaria.

ITN Insecticide-treated net. Bed nets and screens have always been effective barriers against all kinds of pests, but insecticide-treated nets are even more effective due to the added effect of the chemical (usually permethrin) with which they are impregnated. However, these are more expensive than the regular bed nets and also require retreatment with the insecticide every 6 months to remain effective. Regardless, they are an essential tool in protecting against the bites of malaria-causing mosquitoes. Also see LLIN

IPT Intermittent presumptive therapy or intermittent preventive treatment. The concept that proactive care is better than reactive medicine, particularly in the case

of at-risk vulnerable populations. In the case of malaria, IPT has been recommended in certain areas for prevention of infection in pregnant women (IPT_p) and infants (IPT_i), who are particularly vulnerable to malaria mortality and morbidity. Systematically employed only in some African countries, but remains a prophylactic option in other areas of the world.

IRS Indoor residual spraying. The use of a pesticide such as DDT in limited ways and amounts has been recommended by the WHO as an effective vector-control technique. Earlier opposed to the use of DDT, with major restrictions on its production and use, the WHO now finds DDT a valuable tool in malaria-control activities if used for spraying in restricted areas and in small amounts.

Karst A term used for a particular type of topography found in areas of soluble bedrock, such as limestone or dolomite. Since water can dissolve such rock compositions, *Karst* areas are often characterized by sink holes and caves, among other features.

Khal It is a low-lying area as compared to surrounding land (Bangladesh). *Khal* areas are prone to flooding after rains and thus provide a conducive environment for mosquito breeding.

LLIN Long lasting insecticidal nets. These are ITNs that have been treated with a stronger solution of insecticide or in a way that the impregnation of the chemical is much longer lasting than that of regular ITNs. Depending on the fiber and impregnation technique used, the effect of LLINs can last between 3 and 5 years. See ITNs.

Malathion A contact pesticide absorbed into the insect body through the thin skin of the feet to the nerve endings there and subsequently move through the entire nervous system to cause paralysis, and finally death of the insects. Chemically, it is an organophosphate.

MAP Malaria Atlas Project. The aim is to undertake detailed mapping of malaria risk areas as indicated by the global occurrence of malaria. The hope is that this will be able to better guide policy and health planning efforts. The first maps detailing areas at risk to *P. falciparum* infection were released in early 2009 and efforts are ongoing to map the scope of *P. Vivax*. Each mapping will be able to reveal areas of high occurrence, foci of occurrence, nature of malaria, etc. and can dictate more effective strategies for malaria control. See *falciparum* and *vivax*.

MAP Malaria Action Plan (India). The constant fluctuations in malaria incidence in the post-resurgence period led to this revised and updated anti-malaria strategy, with the aim of preventing the recurrence of epidemics and lowering malaria incidence to the greatest extent possible. It became effective in 1995.

MCP Malaria Control Program (WHO). The failure of the Malaria Eradication Program of the 1950s and 1960s brought about the realization that malaria could at best be controlled and contained rather than eradicated. The MCP was launched in 1992 with strategies for vector management, surveillance, prophylaxis and cure, with the hopeful objective of eradication “if feasible.”

MCP Malaria Control Program (country-wise). Most South Asian countries ran their anti-malaria programs in consonance with the WHO, the primary agency directing such efforts and the sponsor of the global Malaria Control Program. Some countries with anti-malaria programs that also had the same titles were Bangladesh and Pakistan.

MCZ Malaria Control Zones (Pakistan). These were created for the purpose of carrying out the WHO-sponsored Malaria Eradication Program (MEP) in Pakistan and were further divided into sectors and subsectors. See MEP.

MDG Millennium Development Goals. Formulated by the United Nations Organization on the eve of the millennium, the goals focus on eight areas of human development and environmental sustainability that are to be met by 2015. Goal 6, Target 3 of the MDGs focuses on halting the further spread and reversing the incidence of malaria by 2015.

MEP Malaria Eradication Program (WHO). A global program launched by the World Health Organization in 1955 with the aim of freeing the world of malaria through vector control, prophylaxis and cure, mainly through the use of pesticides such as DDT and appropriate anti-malarial drugs. Believing malaria to be eradicated or nearly so in South Asia, the MEP was suspended in about 1969, to be replaced by anti-malaria drives and programs more suited to the conditions prevailing then. See MCP.

MEP Malaria Eradication Program (Pakistan). The WHO-sponsored MEP was adopted in various South Asian countries and thus called by similar names in each of the nations, including in Pakistan. Pakistan's program later changed to the Malaria Control Program (MCP) in 1974 in accordance with WHO guidelines.

MIM Multilateral Initiative on Malaria. A multi-sectoral partnership for development of more effective, safe, and cheap drugs and pesticides, and strengthening health-care structures in the fight against malaria.

MMV Medicines for Malaria Venture. A multi-sectoral partnership for development of more effective, safe, and cheap drugs and pesticides, and strengthening health-care structures in the fight against malaria.

MPO Modified Plan of Operation (India). Resurgence of malaria in India and the inefficacy of then existing anti-malaria activities led to a review of these activities and the formulation of a modified plan in 1977. The objectives of the MPO were to prevent deaths due to malaria, reduce morbidity, and focus on bioenvironmental and drug resistance aspects to maintain the successes of previous anti-malaria drives.

MTR Malaria transmission rate. A precise method of computing the incidence of malaria by dividing the number of microscopically confirmed malaria cases in *n* area (in this case, the MCZs of Pakistan) by the population of the respective MCZs. See MCZ.

MTT Malaria transmission trend. The trend or direction of malaria occurrence computed by calculating the moving average of MTRs for a specific number of years (in this case, the years 1973, 1975, and 1978 for Pakistan) for a particular area or MCZ. This moving average for each MCZ is then standardized using total population for that MCZ, yielding the MTT for that area. See MCZ and MTR.

MVI Malaria Vaccine Initiative. Established in 1999 by PATH (see below), seeking to carry out research and trials for a malaria vaccine.

NAMP National Anti-Malaria Program (India). The National Malaria Eradication Program (NMEP) was re-invigorated to follow more aggressive malaria prevention strategies and renamed NAMP in 1999. See NMEP.

NIH National Institutes of Health (USA). It is the nation's premiere laboratory and medical research agency that funds as well as conducts research activities, including related to malaria.

NMCP National Malaria Control Program (India). The categorization of India into hyperendemic and endemic malarial areas led to the undertaking of concerted anti-malarial activities and the establishment of the NMCP in 1953. Also see NMEP.

NMEO Nepal Malaria Eradication Organization. Begun in 1958 to rid the country of malaria by following the recommendations of MEP.

NMEP National Malaria Eradication Program (India). Launched in 1958 under the guidelines of the WHO-sponsored Malaria Eradication Program (MEP). The success of the previously running National Malaria Control Program (NMCP) led to the belief that malaria could be eradicated from the country, leading to the creation of the National Malaria Eradication Organization (NMEO) that was responsible for the functioning of the NMEP. See NMCP.

NVBDCP National Vector-Borne Disease Control Program (India). It was founded in 2003 to consolidate all the anti-malaria-related health drives that were fragmented over various departments and divisions. It also includes all public health drives related to dengue, chikungunya, and other vector-borne diseases common in India.

PATH Program for Appropriate Technology in Health. A Seattle-based health-oriented international non-profit organization working toward finding better solutions for challenges to human health. Among its activities is carrying out research and trials for a malaria vaccine.

***Pf*CP** *P. falciparum* Containment Program (India). A component of anti-malaria drives within the Modified Plan of Operation (MPO) designed specifically to manage and combat malaria caused by the deadly *P. falciparum*. See MPO.

Plasmodium The parasitic agent responsible for causing malaria. It is a single-celled protozoon, and it was implicated as the malaria-causing agent in 1884

by Charles Louis Alphonse Laveran. There are four *plasmodia* that cause malaria: *P. vivax*, *P. ovale*, *P. malariae*, and *P. falciparum*. See *falciparum* and *vivax*.

POP Persistant organic pollutant. Refers to chemicals that do not degrade easily and therefore persist in the environment (e.g., in soil and in water) for long periods of time, ultimately affecting entire ecosystems and entering the food chain. See Stockholm Convention on POPs.

SEAR/SEARO See WHO/SEARO.

South Asia In the context of this book, it refers to the seven countries of Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka.

SP Sulfadoxine-pyrimethamine. A combination therapy for malaria that came into very popular use once the *Plasmodium* displayed resistance to chloroquine, although chloroquine was used in South Asia well into the latter part of the twentieth century. Unfortunately, *P. falciparum* is now resistant to SP in most parts of South Asia, and ACTs are being pressed into use. See South Asia, *falciparum*, and ACTs.

SPR Slide positivity rate or spleen rate. Computed by dividing malaria positive slides by total number of tests, in hundreds.

Stockholm Convention on POPs A worldwide treaty that aims to limit and eventually completely stop the use of POPs in favor of safer alternatives. The aim is to protect the environment as well as public health. It came into force in May 2004 and puts into place control and monitoring mechanisms for its member nations. In relation to DDT, for example, Convention member countries are expected to report every 3 years on the progress in malaria control as well as in finding alternatives to DDT. The Convention lists the following 12 chemicals as the greatest offenders: 12 compounds covered under the Convention are Aldrin, Chlordane, Dieldrin, Endrin, Heptachlor, Hexachlorobenzene, Mirex, Toxaphene, Polychlorinated Biphenyls, DDT, PCDD (Dioxin) and PCDF (Furans). See POP and DDT.

RBM Roll Back Malaria Initiative. By the end of the twentieth century, it became clear to international health leaders that malaria was not just a bioenvironmentally created problem that caused significant health issues, but also was a major player in the vicious cycle of ill health and poverty. It was also realized that containing malaria required continuous surveillance, vigilance, and action. Keeping these aspects in mind, a multi-stakeholder, multi-sectoral partnership of international and national level entities was formed in 1998 to try and tackle malaria on all fronts.

Tarai The plain areas in the southern reaches of the Himalayas lying in Nepal and India. Much of this area was endemic or hyperendemic before being tackled by Malaria Eradication Programs.

Thana Administrative Precinct (Bangladesh). The terminology is no longer in use, and has been replaced by “district”.

UMd/CVD University of Maryland Center for Vaccine Development (USA). Housed within the University of Maryland School of Medicine, the Center conducts research and trials related to many diseases that are of concern to the developing world. Among these activities is research and clinical trials for malaria vaccines.

UMS Urban Malaria Scheme (India). During the period of malaria resurgence in India, it was realized that the disease was increasingly becoming an urban phenomenon. This resulted in the creation of the UMS in 1971, which at the time covered 23 towns. More were added over the years, and the UMS covered 131 of its targeted 181 urban areas by 1998.

UNDP United Nations Development Program. Provides funding and grants-in-aid for various development programs, including those related to anti-malaria.

UNICEF United Nations International Children's Emergency Fund (old) or United Nations Children's Emergency Fund (current), but popularly known only by its acronym. The focus is on providing basic needs and health care to children and their support systems. Among the priorities is malaria, since children, particularly infants and those under 5 years of age are especially vulnerable to malaria.

USAID United States Agency for International Development. Under the US Foreign Assistance Act, the agency is charged with providing humanitarian aid and assistance, monetary and technical, within the purview of the US foreign policy.

Vivax One of the four malaria-causing parasites. It is not as virulent as the *falciparum* parasite, but is much more widespread in occurrence, putting large numbers of people at risk of malaria. It also causes the type of malaria that leaves people prone to reinfection.

World Bank Supranational agency independent of but closely related to the United Nations Organizations. It provides low interest loans to developing countries to undertake various development programs, including anti-malaria activities.

WHO World Health Organization. This is the nodal agency that formulates and implements strategies regarding health, including for malaria control, elimination, and eventual eradication. It often works in partnership with national governments and other stakeholders.

WHO/SEARO South-East Asia Region Office (of the World Health Organization). The WHO operates globally by dividing it into a number of regions. Countries of southern and southeastern Asia lie within the scope of its "Southeast Asia region," which is headquartered at the SEARO at New Delhi, India. Countries within this region include Bangladesh, Bhutan, DPR (North) Korea, India, Indonesia, Maldives, Myanmar, Nepal, Sri Lanka, Thailand, and Timor Leste. See South Asia for comparison.

WRAIR Walter Reed Army Institute of Research (USA). The Institute's focus is on issues pertaining to US military personnel and their environment, but benefit in non-military health situations as well. Their field tests conducted on efficacy of anti-malarial drugs are one such example.

Zoophilic/zoophagic In reference to malaria, this applies to vectors that prefer to feed on animals other than humans.

Contributors

Rais Akhtar Emeritus Scientist, CSIR, Centre for the Study of Regional Development, Jawaharlal Nehru University, New Delhi, India, raisakhtar@hotmail.com

Ashok K. Dutt Emeritus Professor of Geography, Planning and Urban Studies, University of Akron, Akron, OH, USA, dutt@uakron.edu

Hiran M. Dutta Professor Emerita in the Department of Biological Sciences, Kent State University, Kent, OH, USA, hdutta@windstream.net

K. Maudood Elahi Department of Environmental Science and Pro-Vice Chancellor of Stamford University-Bangladesh, Dhaka, Bangladesh, elahikm@stamforduniversity.edu.bd

Adrien Humphreys US State Department, USA

Ishrat Islam Department of Urban and Regional Planning, Bangladesh University of Engineering & Technology, Dhaka, Bangladesh, ishrat_urp@yahoo.com

Jamil H. Kazmi Department of Geography, University of Karachi, Karachi, Pakistan, jkazmi@usa.net

Bishnu Dev Pant South Asian Institute of Management (SAIM), and Director, Centre for Economics and Applied Statistics (CEAS), SAIM, Kathmandu, Nepal, bishnu.pant@gmail.com

Clifford Parera Akron, OH, USA, shiranti@aol.com

Gisela Peters Bad Homburg, Germany, peters.gisela@t-online.de

Sabiha Sultana Department of Geography and Environment, Jahangirnagar University, Dhaka, Bangladesh, iamsabiha.sultana@gmail.com

Vandana Wadhwa Department of Geography and Environment, Boston University, Boston, MA, USA, vandanaw@comcast.net

Iqtidar H. Zaidi (late), formerly of the Department of Geography, University of Karachi, Karachi, Pakistan

About the Authors

Dr. Rais Akhtar is Emeritus Scientist, CSIR, Centre for the Study of Regional Development, Jawaharlal Nehru University, New Delhi. He has published more than 12 books and numerous articles on medical geography and has taught at various national and international universities. He is the recipient of the Leverhulme Fellowship (University of Liverpool), Henry Chapman Fellowship (University of London), and the University of Sussex Visiting Fellowship. He was lead author (1999–2007) for the Intergovernmental Panel on Climate Change, which was the joint winner of Nobel Peace Prize for 2007. His research interests include environmental change and health, medical geography, and geoecology of malaria.

Dr. Ashok K. Dutt is Professor Emeritus of Geography, Planning and Urban Studies at the University of Akron, Ohio. He received his doctoral degree from Patna University and diploma in comprehensive planning from the Institute of Social Studies, The Hague. Dutt has edited and authored 24 books and has published about 300 articles, book chapters, and entries in encyclopedias relating primarily to urbanization, planning, cultural, and medical geography, with groundbreaking contributions in the areas of malaria ecology and AIDS diffusion patterns. He has been a Fulbright Scholar and Ford Foundation Fellow, received the R.N. Dubey Foundation Award for Lifetime Achievement in Geography, and was honored with the title of *Bhugool Bachaspati* (Most Learned Geographer) in 2008 at the National Congress of National Association of Indian Geographers.

Dr. Hiran Dutta is Professor Emerita of Biological Sciences, Kent State University, Kent, Ohio. She received her doctoral degree from the Leiden University, The Netherlands. She has authored and edited three books, published over 70 articles in major journals of the world including a large number on malaria and AIDS, various encyclopedia entries, and is also an editor of a scientific book series. Her latest contribution in medical geography is as co-author of a chapter entitled "*From Black Death to Surat Plague: A Quantum Leap in Medical Science Development*" (Prentice Hall 2008). Apart from her professorial and mentoring work, Dr. Dutta directed an exchange student program between the Kent State University and the Leiden University, The Netherlands from 1998 through 2003.

Dr. K. Maudood Elahi is Professor in the Department of Environmental Science at Stamford University, Bangladesh and Pro-Vice Chancellor of the same university. He has also taught at Jahangirnagar University, Dhaka and acted as the Pro-Vice Chancellor of the National University, Bangladesh. He obtained his Ph.D. from Durham University, UK and has collaborated on numerous studies related to environment, health, and natural disasters. He has served on the census wing of the Bangladesh Bureau of Statistics and the task force on Flood Action Plan for the Government of Bangladesh and been associated in various capacities with a number of national and international professional organizations including Bangladesh Association for the Advancement of Science, the International Geographical Union [IGU], Center for Migration Studies (USA), and International Organization for Migration (IOM), Dhaka/Geneva.

Dr. Adrien Humphreys currently works for the United States Department of State. She has published various articles and chapters on sustainable development and economic planning, and is the author of *Urban Ecological Research Methods Applied to the Cleveland, Ohio Metropolitan Area* (Edwin Mellen Press 2002). Her primary research interests relate to urban affairs.

Dr. Ishrat Islam is Assistant Professor of Urban and Regional Planning at the Bangladesh University of Engineering & Technology, Dhaka. A trained architect and planner, she has published several journal articles on urban and environmental issues, sustainable development, and architecture. She is the author of the book *Wetlands of Dhaka City* (A H Development Publishing House 2009). She is an executive committee member of Women Architects, Engineers and Planners Association (WAEPA).

Dr. Jamil H. Kazmi is Professor in the Department of Geography, University of Karachi, Karachi, Pakistan. He received his doctoral degree from Karachi University and completed his postdoctoral term from University of Georgia, Athens, Georgia in 1999 under the Senior Fulbright Program. He has published extensively in journals of international repute in the area of his research interests such as the application of geoinformatics in disease ecology and environmental modeling.

Dr. Bishnu Dev Pant is Professor at the South Asian Institute of Management (SAIM) and Director of its newly established Centre for Economics and Applied Statistics (CEAS). He received his Ph.D. from the Indian Statistical Institute, going on to serve as statistics advisor to the National Planning Commission of the Government of Nepal, and chief of the Statistical Information Services Section in the United Nations Economic and Social Commission for Asia and the Pacific (UN-ESCAP), Bangkok. He then served at the Asian Development Bank (ADB), Manila in different capacities for more than 12 years since April 1996, including as regional coordinator of the International Comparison Program for Asia and Pacific region, and director of Development Indicators and Policy Research Division in the Economics and Research Department before joining SAIM.

Dr. Clifford Parera is a medical doctor (MD) residing in Akron, Ohio where he has practiced psychiatry for almost 40 years. He received his medical degree from

the University of Colombo, Sri Lanka. During his education and initial years of practice in Sri Lanka in the late 1960s, he encountered many malaria patients, providing him excellent first hand knowledge of both diagnostic and treatment details.

Dr. Gisela Peters is an Independent Research Scholar, Bad Homburg, Germany. She was awarded her Dr. rer. nat. in 1982 in geomedicine. Following this, she turned her attention to communicating geomedical topics and wrote scientific articles for specialist periodicals and also edited video, audio, and text for an American publishing company. From 1988 to 2003 she built up the life science department covering PR for medical, pharmaceutical, and dental products for Heraeus, a German industrial company. Following this she specialized in dentistry. She has been a freelance scientific author since 2003 and specializes in dental health, dental medicine, and dental technology.

Dr. Sabiha Sultana is Professor in the Department of Geography and Environment at Jahangirnagar University, Dhaka, Bangladesh. She received her education at University of Dhaka and University of Bristol, UK. She has contributed papers in numerous books and journals at home and abroad and has participated in a number of national and international conferences/symposia in the areas of her research interests, which encompass settlement geography, human ecology, housing, and land use transformation. She is a member of various national and international professional societies, including the Bangladesh Association for the Advancement of Science and corresponding member of the Working Group on Urbanization in Developing Countries of the International Geographical Union [IGU].

Dr. Vandana Wadhwa is Lecturer at Boston University, Massachusetts, USA. She has published numerous articles in major journals, contributed various books chapters and encyclopedia entries and co-edited a comprehensive volume entitled "*Facets of Social Geography*" (Cambridge University Press 2010). She also has experience working in the field with Indian and US NGOs and non-profit organizations, particularly in the areas of social planning and civil rights. Her research interests lie in human geography including disability studies, health and medical geography, feminist and masculinity studies, and development issues. She is the former chair of the Health & Medical Geography Specialty Group and Regional Development and Planning Speciality Group of the Association of American Geographers, and current Executive Board member of its Asian Geography Speciality Groups and Disability Geography Speciality Group.

Dr. Iqtidar H. Zaidi (late) was Chair and Professor at the Department of Geography, University of Karachi, Karachi, Pakistan. He received his Ph.D. from University of Syracuse, New York, USA during the 1960s under the Fulbright Scholars Program. He has published more than 50 articles on issues of environment, ecology, and political geography. He died at the age of 72 in 1999 in Karachi, Pakistan.

Chapter 1
The History and Progression of Malaria: A Global and Regional View

Vandana Wadhwa, Ashok K. Dutt, and Rais Akhtar

Popes died, kings sweated, Tsars shivered, regional populations were decimated, and armies laid waste by the tiny plasmodium with Anopheles alliance.

(Schlagenhauf 2004, p. 191)

Abstract Malaria remains one of the worst killers in the world today and is the cause of even greater suffering in human, social, and economic terms. This chapter seeks to introduce the reader to various facets of this age-old disease, including malaria disease ecology, the course of malaria occurrence and diffusion over the ages, and the various traditional and public health measures that have been used for protection, prevention, and cure. The chapter focuses specially on the twentieth century, when a better understanding of the disease and various scientific advancements led to its near eradication in many parts of the world, including South Asia. These advances included anti-malaria drugs, pesticides such as DDT, better public heath measures, and the quest for an effective vaccine. Meanwhile, not only has South Asia faced resurgence in malaria occurrence since the 1960s and 1970s, but global trends in malaria mortality and morbidity discussed in this chapter reveal that most tropical regions of the world have been unable to loosen malaria's grip on them even today. An overview of what the rest of the book will discuss rounds out this introductory chapter.

Keywords Malaria ecology · Anti-malaria drugs · DDT · Vaccines · South Asia · Resurgence · Malaria—twentieth century

Malaria has existed since millennia and has plagued and perplexed humankind for an equally long time. All the development and progress in science has not been able to conquer this disease, although it has been held at bay for at least half a century in many areas of the world. However, South Asia is not among these

V. Wadhwa (✉)
Department of Geography and Environment, Boston University, Boston, MA, USA
e-mail: vandanaw@comcast.net

R. Akhtar et al. (eds.), *Malaria in South Asia*, Advances in Asian Human-Environmental Research 1, DOI 10.1007/978-90-481-3358-1_1,

areas—its conducive climate, lack of resources, and fluxes in political will and stability have rendered it highly malaria prone. Considering that this risk of malaria persists to this day despite multiple and sustained efforts, we feel it is imperative to examine the South Asian region's past experience in order to mount an informed and organized offensive to combat malaria. This book is an effort in the direction of such an examination of malaria occurrence in South Asia in the latter part of the twentieth century, characterized by near eradication and subsequent resurgence. We believe that the study of spatio-temporal patterns of such occurrence will better equip us to deal with malaria as it occurs today. Therefore, this book is also future oriented, applying past lessons to the present and concluding with current and forthcoming efforts toward malaria control in the realms of science and policy.

Narain (2008, p. 1) aptly sums up the import of the exercise:

> The focus on Africa was understandable due to the burden it suffers; nearly 90% of the estimated one million preventable malaria deaths occur in Africa. It is however a myth that malaria is a problem of Africa only. Clearly, malaria and other vector-borne diseases pose a huge problem in Asia, particularly the 11 member countries of the South-East Asia (SEA) Region[1] and deserve due attention both at the national and international levels. . . .as a staggering 687 million people are at high risk for malaria, with an estimated 90–160 million infections and more than 120,000 deaths occurring each year.

Malaria Goes Global: A Brief History

In ancient times, diseases existed in isolated "pools" due to the infrequency of interregional interaction between population groups. However, between 500 BCE and 1,200 CE, the disease pools spread and diffused rapidly all over Eurasia due to increased trade and migration activities (Dutt and Dutta 1986, p. 38). Following the first wave of globalization and European colonization in the fifteenth century, the discovery and founding of new land and sea trade and migration routes led to further diffusion of these "pools," which then coalesced over larger areas of the world; malaria being a prime example of such diffusion and coalescence (Dutt and Dutta 1986; Schlagenhauf 2004). Figure 1.1 illustrates the global occurrence of malaria toward the end of the twentieth century.

Malaria is thought to have originated in West Africa and initially spread to Europe and Asia along human migratory and trade routes (Carter and Mendis 2002; Desowitz 1991; Dutta and Dutt 1978). Malaria has also been described in ancient Chinese texts as long as 5,000 years ago (around 3,000 BCE) and in tablets from the Sumerian empire (Carter and Mendis 2002; Desowitz 1991). It possibly spread to Egypt when the latter was at the height of its civilization, probably as a result of Egyptian conquests and the constant influx of migrants and traders into Egypt. It is speculated that malaria would have been carried to areas of the Greek Empire (including erstwhile Persia and parts of India), and later to Rome when the latter occupied Egypt (Dutta and Dutt 1978), thriving due to the naturally conducive environs for mosquitoes. There is also mention of fevers that seem typical of malaria

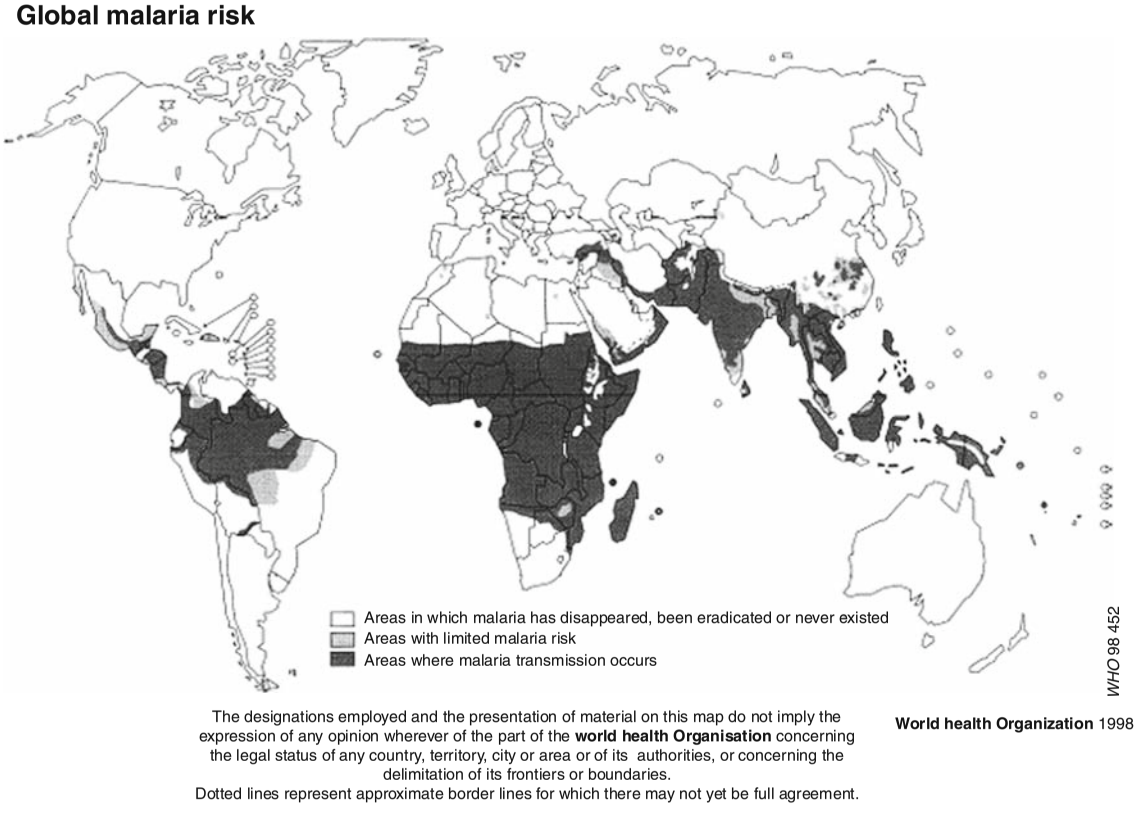


Fig. 1.1 Global malaria spread and occurrence in terms of global malaria risk
Source: Modified from World Health Organization (2000), Twentieth Report of the WHO Expert Committee on Malaria. WHO Technical Report Series 892. Available from WHO website http://apps.who.int/malaria/docs/ecr20_2.htm, retrieved October 30, 2008.

in ancient Indian writings dating back approximately 3,000 years ago (Carter and Mendis 2002; Desowitz 1991; Centers for Disease Control [CDC] 2004), suggesting that malaria was well established in the area by that time. In fact, as long ago as circa 500 BCE, the ancient Indian medical scholar, *Susrata*, implicated the mosquito as the cause of such fevers (Poser and Bruyn 1999). Schlagenhauf (2004) provides a detailed and interesting account of the global spread of malaria, sourcing it to East Africa, from where it spread along the Nile Valley to Egypt, the Levant, and finally into Asia and Europe.

North America was already settled and had a high level of civilization before Columbus arrived in 1492. However, with Columbus' landing, a large number of infectious diseases were carried in, including malaria. It entered the so-called New World with an even greater magnitude with the start of the slave trade, which occurred first to the Caribbean in the sixteenth century and then to mainland North America in 1619. During the slave trade, thousands of forced laborers were brought in from hot and humid West Africa, who carried in malaria with them (Desowitz 1991; Dutta and Dutt 1978; Packard 2007; Schlagenhauf 2004). Thus, by the seventeenth century, malaria had become a global disease.

Dutta and Dutt (1978) provide a global perspective on the ecological causes of malaria occurrence. Temperatures between 15°C and 30ºC (59–86ºF) and a relatively even year-round occurrence of rainfall ranging from 30 to 60 in. per year (45–90 cm) are climatic characteristics conducive to malaria occurrence. Lower altitudes and waterlogged areas are some additional physical features that are suitable to the breeding of mosquitoes, the malaria vector. Thus, it follows that the equatorial and tropical zones of the world are the most prone to the occurrence of this disease.

Malarial Cycle: Agent, Vector, and Host

In order to understand the occurrence of this disease, it is important to understand the malarial cycle in which the various players were identified through the work of several scientists. Two such scientists stand out through the significance of their contributions. Charles Louis Alphonse Laveran (1845–1922) was a French army surgeon during the Franco-Prussian War. He was the first to recognize the malaria parasite in the red blood corpuscles of infected malaria patients. By 1884, he had collected enough evidence to be able to identify the malaria parasite. However, his work went unrecognized for a time, but was finally rewarded with a Nobel Prize in 1907 for the identification of the malaria-causing protozoa (Arrow et al. 2004; Lambert 2003).

Ronald Ross discovered the cause of malaria transmission in 1897 as a result of his experiments in Secunderabad, Andhra Pradesh (AP), India. Ross was able to prove that the *Anopheles* mosquito was responsible for the transmission of malaria when he isolated malaria cysts in the stomach wall of the *Anopheles* mosquitoes that had fed on a malaria patient. Later, in 1898, he carried on his work in Calcutta (now Kolkata), and using avian hosts, further discovered the mechanism of transfer

of the parasite from the mosquito's stomach wall to its salivary glands and further on to the host. His work won him the 1902 Nobel Prize for medicine (CDC 2004b; Desowitz 1991; Dutta and Dutt 1978).[2] May (1961) summed up the disease ecology of malaria as the interaction between the environment and the triad of agent, vector, and host. It is in this context that the occurrence of malaria is discussed below.

Agent

Malaria is caused by a protozoan parasite; the *plasmodia* that cause the disease are of four major types (*Plasmodium falciparum, P. vivax, P. malariae*, *and P. ovale*), each of which causes a different variation of malaria. The *plasmodia* exist either inside the mosquito or the human body and are thus not directly influenced by the physical environment, although temperatures below 15°C (59°F) and above 32°C (90°F) do retard the development and survival chances of the parasites (Dutta and Dutt 1978). However, even between these temperatures referred to, duration of maturation of the parasite in the mosquito can be strongly affected (E-mail communication with Dr. David Bradley, September 1, 2009).

The malarial cycle begins when the mosquito injects *sporozoites* (cells that cause infections) into the human bloodstream during the process of its blood meal. *Sporozoites* then enter a series of developmental stages, progressing from their initial stage as small spores into a mature multi-cellular state. Specifically, the *sporozoites* are carried in the blood stream to the liver, where they grow into *trophozoites* (active feeding-stage cells) and then develop into *schizonts* (mother cells) for asexual reproduction. They go on to divide into *merozoites* (daughter cells), invade red blood corpuscles (RBCs), and eventually break out of the damaged RBCs only to invade new ones, causing the typical malaria symptoms of chills and fever. After a time, some of the *merozoites* entering the red cells develop and differentiate into male and female gametocytes, which enter the mosquito as it feeds again. The female gametocyte is fertilized in the stomach of the mosquito, where it lodges in the stomach wall as a small cyst, called an öocyst. The öocyst divides to form *sporozoites*, which then move to the salivary glands of the mosquito, and the entire cycle begins again. Parasite viability depends upon favorability of environmental conditions for the vector (mosquito), on the availability of food, or access to human blood (Dutta and Dutt 1978).

Vector

The genus *Anopheles* is the malaria vector, although only about 30–40 of its more than 400 species are actually malaria-transmitting vectors (CDC 2008). Only the female *Anopheles* is equipped to be hematophagous due to the presence of the piercing mandibles and maxillae, which puncture the skin, thus allowing for a blood meal. South Asia is home to a number of species of the *Anopheles* mosquito,

each of which thrives under different temperature, rainfall, topographical, and other environmental conditions. Some common species are *A. annularis, A. culicifacies, A. dirus, A. fluviatilis, A. minimus, A. philippinensis*, *A. stephensi,* and *A. sundaicus*. Finding ideal conditions for its species, the female *Anopheles* deposits it eggs on the surface of a suitable water body. The larvae feed at this surface level and develop into pupae, and finally metamorphose into adults. This entire cycle takes about 24 days, although weather variations may affect the length of this cycle (Dutta and Dutt 1978).

Host

The human host houses the parasite during its reproductive stage and is an important link in the continuation of the malarial cycle. Humans, who bear untold social and economic cost due to the parasite, are highly instrumental in aggravating or retarding the spread of the disease through their various activities. Some cultural practices that affect the spread of malaria are:

1. dietary restrictions (affects nutrition and resistance capacity);
2. sleeping outdoors, and types of housing;
3. cultivation of certain crops (e.g., traditional methods of rice cultivation are associated with malaria occurrence);
4. economic aspects such as underdevelopment (leading to malnutrition and less access to medicine); and
5. political upheavals (might disrupt anti-malaria programs).

Access to potable water (affects overall health), adequate levels of sanitation and proper drainage (among other factors, affects vector breeding), prophylactic measures such as anti-malarial drugs and vaccinations for other diseases that might compromise a body's immune system, use of chemicals such as pesticides where appropriate, and investment into research and control of diseases are aspects that retard the spread of malaria. Traditional and modern medical facilities and know-how and health-care planning as determined by governmental policies also contribute to the curtailment of the disease. Much of the causative uncertainties of malaria may be handled by bringing economic and political stability to a region, since it would ensure better levels of nutrition and public health, and greater access to medical facilities (Dutt and Dutta 1986).

Breakthroughs of Science in the War Against Malaria

While the *Anopheles* mosquito has proved itself a worthy foe, eluding control and eradication efforts time and again, humans have also kept up on this long battle. It was mainly in the twentieth century that the discovery and formulation of many new

chemicals, drugs, public health policy, and science-based understandings of malaria were witnessed on a major scale. Some of the most significant scientific and public health breakthroughs are discussed in this section.

Public Health and Protection Measures

Ever since humans became aware of the breeding habits of mosquitoes, public health and sanitation measures have been underway. Most of these have focused on the "two arms" of malaria control: (a) vector destruction and control through limiting its habitat and attempting to destroy the vector itself and (b) case management through prophylaxis and treatment (Gardiner et al. 2005). Vector control measures have included draining of swamps and water, filling of ditches, de-weeding and clearing of underbrush, as well as oil applications to water bodies, to name a few. Two of the most innovative and effective measures adopted to prevent contact with the vector have been the use of door and window screens and of bed nets.

Most cultures have had their own method of keeping pests at bay. Literature records that the ancient Persians used pyrethrum (derived from the plant *Chrysanthemum cinerariaefolium*) as a pesticide, and other cultures such as the Greeks and Romans used "gauze, muslin, and fishing nets" to keep out a variety of insects (Schlagenhauf 2004). In nineteenth-century USA, windows were often screened with cheesecloth in order to keep insects and other undesirable elements outside the home. In the early 1860s, Gilbert & Bennett Mfg. Co. of Georgetown, Connecticut, a wire cloth manufacturer, was shut down as a result of the civil war. With large amounts of inventory left over, an employee began marketing its wire meshing as a replacement for the cheesecloth window screens (Colley n.d.). The durability and efficacy of the product made it extremely popular and has since proved to be a valuable protective measure against insect invasion into homes.

Bed nets have been in use for a long time by many peoples, and while they are a fairly effective measure of personal protection, it is still possible for mosquitoes and other insects to bite through them. Therefore, insecticide (usually permethrin)-treated mosquito nets (ITNs) are now favored over untreated ones. The protective effect of the insecticide extends not only to the user, as is recommended for high vulnerability groups such as infants and pregnant women, but also forms a general protective umbrella for entire communities when ITNs are used by a larger section of the population as has been seen in various villages and communities in Africa (Killeen et al. 2007; Gimnig et al. 2003). "ITNs can protect not only the individuals and households that use them, but also members of the surrounding community . . . because they kill adult mosquitoes directly or force them to undertake longer, more hazardous foraging expeditions in search of vertebrate blood and aquatic habitats." (Killeen et al. 2007, para 3). However, ITNs cost more than untreated bed nets and have to be re-treated every 6 months, making financial access to them more difficult, particularly for those in developing countries, most of whom have the greatest

need and the least resources. While better technology has resulted in the ability to produce longer lasting insecticidal nets (LLINs) that are effective for 3–5 years depending on strength of the impregnating solution, fiber used, and washing frequency, most people in affected areas will still find these difficult to access, both financially and otherwise, unless effective and affordable distribution is achieved by well-coordinated efforts of various international agencies (see WHO 2008b).

DDT: A Potent Mosquito Killer

The role of DDT in the battle against malaria has been an important and controversial one. DDT (dichlorodiphenyl trichloroethane) is an organochloride insecticide used mainly to control mosquito-borne malaria and as an agricultural insecticide. Available in various different forms, this colorless and water-insoluble substance provides many options for methods of use. For many years it had been used as a very potent pesticide (Dutta and Dutt 2007).

DDT was first synthesized in 1874, and in 1939, the Swiss scientist Paul Herman Müller discovered its use as an insecticide. He was awarded the Nobel Prize in 1948 for his work. DDT was widely used by the Allied Forces during the Second World War in the malaria-prone jungles of South and Southeast Asia. After the war, from the 1940s to the 1970s, it was also used as an agricultural insecticide in many developed countries (Rogan and Chen 2005). The low cost, effectiveness, persistence, and versatility of this chemical made it a popular option all over the world, and it was widely used in South Asia for killing mosquitoes. As a result, malaria was almost eradicated in this region by the late 1950s and early 1960s (Dutta and Dutt 2007).

However, this widespread use of the pesticide would prove to be its undoing and the cause of much of today's malaria burden: over time, mosquitoes developed a resistance to DDT, contributing partly to the resurgence of malaria in South Asia in the 1960s. Internationally, US biologist Rachel Carson's 1962 book, *Silent Spring*, bears significant mention in that it was instrumental in making the case against DDT in the minds of the American public, and despite her emphasis on least possible use rather than either extreme of use, the public, even on an international scale, became caught up in an environment of fear related to DDT use.

Although there is no concrete evidence of high DDT toxicity to human beings, DDT in large amounts was found to be toxic to the environment, resulting in a ban on its widespread agricultural use as a pesticide in most countries, particularly so in the developed world. However, there remained an allowance for its use in particular public health situations (Handwerk 2006; Thacker 2002; Rogan and Chen 2005; Ware and Whitacre 2004). Despite the ban in the developed countries, many developing countries, particularly Africa and other tropical regions, continued to combat mosquito-borne malaria with the help of this powerful pesticide, even though there are still some lingering questions and findings regarding its safety to humans that

can only be resolved through further research (Curtis and Lines 2000; Rogan and Chen 2005).

The Stockholm Convention on Persistent Organic Pollutants (POPs—of which DDT is one) that came into force in May 2004 emphasizes that such chemicals are harmful to the environment since they persist in the environment and should thus be used sparingly and under stringent regulation and reporting guidelines. The Convention also acknowledged the need for some counties to continue to use it in a regulated manner for indoor residual spraying (IRS). The WHO recognizes that if DDT is used in specific and limited ways prescribed for IRS, the pesticide would help greatly in disabling the malaria vector's capacity to spread the disease (WHO 2005, 2006; see Wadhwa and Dutt, Chapter 10, this book for details).

In 2006, Tanzania lifted its ban on DDT, making a case for the resumption of DDT use as a standard procedure in malaria control, arguing that the benefits would far outweigh the risks. The Tanzanian Health Minister, David Mwakyusa said, "We have been forced to reconsider the use of DDT to try to save the lives of our people" (quoted in *Independent Online*, 8 May 2006 as cited in Taylor 2006). Several other African countries have since followed suit (Taylor 2006).

Thus, in the developing world, DDT remains a potent weapon in the anti-malaria arsenal. More information on recent developments regarding DDT-use policies is provided in Chapter 10.

Anti-malarial Drugs: A Brief History

Traditional civilizations have long used local flora to treat symptoms of ague and malaria. Peruvian natives used the medicinal bark (*Quina quina* or bark of barks) of the Myroxylon tree to relieve and cure patients of malaria, although some contend that malaria was not present in the region in pre-Columbian times (see Schlagenhauf 2004). Nevertheless, the popular story goes that when the Countess of Chinchon, wife of the Viceroy of Peru was successfully treated with it while severely ill from the disease, the substance was named Cinchona in her honor. Extracts of the bark were brought to the Europe in the seventeenth century by returning Jesuit missionaries. This same substance is now known as the highly effective anti-malarial drug quinine, which was isolated from the bark of the Cinchona tree in 1820 by French chemists Pierre Pelletier and Joseph Caventou (Arrow et al. 2004, 130; Cartwright 1972, 141; CDC 2004).

Libations of quinine water were thought to bring about a protective effect from malaria and was widely used for malaria treatment into the 1930s. It continues to be used today in many parts of the world for cases of severe malaria (Lambert 2003; McPhee et al. 2008; e-mail communication with Dr. David Bradley, September 1, 2009). Colonial powers sought to import the Cinchona plant to other regions, particularly to Southeast Asia in order to promote accessibility to the medicine. The onset of the First World War saw the disruption of Germany's supply of quinine, and it

scrambled to produce another anti-malarial drug. One such formulation was developed in 1932, in the form of Atabrin (quinacrine, mepacrine) (Arrow et al. 2004, 131; Lambert 2003). On the other side, the Allied troops used the same formulation under the name of Alebrin (Lambert 2003).

While mepacrine was more effective than other previous quinine substitutes, it had various adverse effects, which led to continued research toward finding a safe and efficacious anti-malarial drug. Success came in 1934 with the formulation of Resochin and later Sontochin, both from a class of compounds known as four-amino quinolines. Resochin (chloroquine) was discovered in 1934 by Hans Andersag, a German scientist working at the Bayer I.G. Farbenindustrie A.G. laboratories in Eberfeld, Germany. However, German scientists mistakenly assumed Resochin to be as toxic as the other drugs, and the formulation was not used on any large scale until Second World War (Arrow et al. 2004, 131; CDC 2004). By this time the Allied forces had found access to Sontochin's formula, and making minor modifications, used it as the drug chloroquine. It was only later they realized that their formulation was the same as Resochin (Arrow et al. 2004, 131). This formulation was used extensively during the Second World War, conferring a high level of protection against malaria to allied soldiers fighting in South and Southeast Asia. It has since been used well into the late twentieth and twenty-first centuries as an effective, safe, and low-cost way to combat malaria, until resistance of the malaria *plasmodium* to its effect was noticed in a growing number of areas in both Asia and Africa (Arrow et al. 2004, 131; CDC 2004; Lambert 2003).

Sulfadoxine–Pyrimethamine (SP) use was started in 1967, in the hope that this combination of two anti-malarial chemicals would be able to overcome the problem of *plasmodium* drug resistance that was observed to develop quickly to most anti-malarials in noncombination formulations, although plasmodium resistance to chloroquine has taken much longer to develop as compared to other antimalarials. However, as with the rest, *P. falciparum* developed resistance to SP within a year in the region where it was introduced (Southeast Asia), although it continued to be effective in Africa until the late 1990s (Arrow et al. 2004, 132). Drugs such as Mefloquine (Larium), Halofantrin (Halfan), and Atovaquone–Proguanil Hydrochloride (Malarone) were introduced in the 1970s, 1980s, and 1990s, respectively. Depending on their half-life, they are used for treatment and/or prophylaxis. Mefloquine and Halofantrin have already been associated with *plasmodium* resistance as well as adverse side effects. While Malarone fares better so far with adverse effects, it is presently neither an economically viable option nor immune from resistance, as the first signs of *falciparum* resistance are becoming apparent in Central Africa (Lambert 2003; Wichman et al. 2004).

Another traditional remedy that has proved immensely promising was derived from the Qing-hao plant (sweet wormwood) indigenous to China. Its anti-malarial properties were described in the second-century BCE and its active ingredient isolated by Chinese scientists in the early 1970s. Better known as Artimisinin, it has become a very valuable tool in malaria treatment and prevention, since it had not produced any significant indications of resistance by the malaria parasite (Arrow

et al. 2004, 133; CDC 2004). It is hoped that Artimisinin-based combination therapies (ACTs) can deal with the issue of *plasmodium* resistance to other single and combination drugs such as chloroquine and SP respectively, particularly in the case of *P. falciparum*. To that end, one of the ACTs introduced recently in 2007 was the combination drug ASAQ. A combination of artesunate and amodiaquine, two of the most effective anti-malarial drugs, ASAQ has the additional benefit of being available at a price just under $1.00 (Cheng 2007). This is a hopeful development in that it brings effective treatment within financial reach of the large populations that live at malaria risk in the developing countries of the global south.

At the same time, Southeast-and-Southcentral Asia, which has been proposed as a possible source area for malaria by some scholars (see Schlagenhauf 2004), has historically and ironically also been an area where the first signs of drug resistance by the malaria-causing parasite have been centered ever since modern medicine has been battling the disease. From chloroquine to SP and now the latest ACTs, this region has always been the first to reveal signs of slowing efficacy or complete failure of anti-malarial drugs due to the *plasmodium's* resistance—the first signs of *P. falciparum* resistance to ACTs have become apparent in some small areas of Southeast Asia since 2007, where the rapidity of its effect has been seen to slow down (McGivering 2009; Sallares 2002). South Asia has only recently begun the use of ACTs, and monitoring will be required to gauge its efficacy in this region in the time to come (Sinha 2009).

Proactive Measures: The Role of IPT

A concept that has gained ground since the mid-1980s in the case management arena is that of intermittent presumptive therapy or intermittent preventive treatment (IPT). This is recommended in areas of stable endemic malaria for particularly susceptible populations such as pregnant women, and at times, infants. The World Health Organization (WHO) backs the use of this type of treatment to bring down high rates of malaria mortality and morbidity that would otherwise result in both mother and child in the absence of such treatment. A combination drug, Sulfadoxine–Pyrimethamine (SP) has typically been used, particularly before *plasmodium* resistance to it became more widespread, administered in at least two full treatment doses during the second and third trimesters of pregnancy (WHO 2008; White 2006). Currently, IPT is practiced in Africa and some countries of Southeast Asia and South America, although its systematic use in pregnancy is restricted only to 45 African countries (White 2006; WHO 2008). While it continues to be a viable chemoprophylactic option should the need arise in other areas, this strategy needs to be deployed wisely, since overuse or misuse of IPT might lead to complications such as greater drug resistance and other unintended consequences (White 2006).

Although cure and prevention of malaria as modern medicine knows it has developed primarily in the period of the last 100 years, malaria still requires immediate

diagnosis and treatment, otherwise the results are death, debility, and other physical impairment. The World Health Report 1999 sums up the situation as follows:

> If malaria is diagnosed and treated promptly the infection may quickly subside, but without effective treatment, severe complications—such as cerebral malaria, severe anaemia or multiple organ failure—can rapidly develop, leading to case fatality rates of 10–30%. The progression from mild symptoms to death can be rapid. Mortality is not the only problem. With hundreds of infective bites per person/year leading to frequent illness, morbidity is high. Serious long-term neurological disabilities are experienced in 10% of children hospitalized in Kenya with severe malaria. Less obvious disabilities, including impairment of cognitive development, are probably even more common. (WHO 1999a, p. 50)

However, there is still hope for a still more effective drug. Work by three separate teams of scientists, one at Santa Clara biotech company Affymax Research Institute and two at the National Institute of Allergy and Infectious Diseases (NIAID), found that "the malaria parasite avoids detection by the immune system by switching between as many as 150 genes, each encoding a different version of a protein known as EMP-1 (for erythrocyte membrane protein 1)"[3] (Nowak 1995, p. 755). The search for the next viable anti-malarial medicine may come from this understanding of the parasite's extraordinary capability of evading the host's immune response that, according to the teams, is essential to its role in causing the disease. The eventual hope is that the findings of the research can help develop a new type of anti-malarial drug "that can keep EMP-1 from attaching red blood cells to blood vessels" (Nowak 1995, p. 755).

The Elusive Vaccine

> It's easy to list every vaccine that can prevent a parasitic disease in humans. There is none. Vaccines exist for bacteria and viruses, but these are comparatively simple organisms. The polio virus, for example, consists of exactly 11 genes. *Plasmodium falciparum* has more than 5,000. It's this complexity, combined with the malaria parasite's constant motion—dodging like a fugitive from the mosquito to the human bloodstream to the liver to the red blood cells—that makes a vaccine fiendishly difficult to design. (Finkel 2007, p. 62)

According to Gardiner et al. (2005), a malaria vaccine would provide a powerful "third arm" for the battle against malaria. Work on a malaria vaccine has been in progress since at least the latter half of the twentieth century, when in 1967, Dr. Ruth Nussenzweig of New York University's (NYU) School of Medicine demonstrated that introducing irradiated and thus weakened (attenuated) form of the malaria-causing *plasmodium* could produce an immune response in mice, without causing the disease itself. This has been the basis for many further attempts in developing a pre-erythrocytic stage,[4] radiation-attenuated malaria vaccine, which continue even today (Finkel 2007; NYU Medical Center/NYU School of Medicine; Wallis 1984; see Wadhwa and Dutt, Chapter 10, this book, for details).

One of the first signs of hope of finding an effective vaccine against malaria in humans came when Colombian researcher Manuel Pattaroyo and his colleagues developed SPf66 in 1987, which seemed to generate promising results in fighting

P. falciparum infections. Initially, this vaccine had shown heartening outcomes in clinical trials conducted in Latin America and Tanzania (Desowitz 1991; Hudson 1995). In the latter trial, a 2-year test found that the vaccine "could cut the risk of clinical malaria in children by almost one-third" (Hudson 1995, 46). However, later trials in Africa cast a shadow of doubt on that optimism (D'Allesandro et al. 1995). Citing research on these trials, Hudson (1995) says:

> According to the Lancet, British doctors have downgraded their optimism about the world's first malaria vaccine, saying it offered no significant protection in newly run trials on children in Gambia.
> The doctors, from the London School of Hygiene and Tropical Diseases, reported that a three-and-a-half month trial on a random sample of 630 babies and young children in the West African country were not encouraging, although they cautioned that special factors could have influenced the results (p. 46).

The problem facing the scientific community is that of "antigenic variation," the ability of the parasite to change its "signature proteins" in a manner and frequency that keeps it ahead of the host's immune response against it (Hudson 1995). Although speaking in the context of anti-malarial drug development, Nowak (1995, p. 755) summarized the problems presented by this variability with the following words:

> . . . about one in every 50 of a new generation of parasites secretes a different EMP-1 [erythrocyte membrane protein], . . . As a result, these altered parasites can dodge the immune responses that had been mounted against the original parasites, allowing them to set off a new wave of infection, and to lodge in the blood vessels of the brain and other organs.

Since then, many more vaccines have been developed—by the end of the twentieth century, several vaccine development initiatives were attempting to take advantage of the new understanding provided by the DNA decoding of the malaria parasite. For example, MuStDO 15.1 and MuStDO 5 (for multi-stage DNA-based vaccine operation) aimed to reduce malaria mortality and morbidity in African children—so far the clinical trials have not been very promising (WHO 1999a; WHO n.d.). Another vaccine is RTS,S (WHO 1999a, 60), a "recombinant protein" vaccine, which might be explained as genetic engineering performed through gene splicing, resulting in rendering the malaria parasite ineffective in transmitting malaria due to the immunogens produced by the newly introduced foreign genes.

RTS,S seems to be the strongest vaccine candidate so far, with better degrees of success in conferring protection against malaria than seen in other vaccine trials (WHO n.d.; Alonso et al 2005, Bojang et al. 2001). However, it will not be ready for licensure until 2010 at the very least, until further trials have been conducted for its efficacy and safety (BBC News 2004). Even more recent efforts in vaccine and drug development through gene study and manipulation of *Anopheles* mosquitoes and the malaria-causing *plasmodium* continue to be underway, as is discussed in the final chapter. Hope for the development of a new, more effective vaccine exists, but not in the immediate future. At present, prevention and control measures seem to be the best course of action.

Trends in Malaria Occurrence

According to the World Malaria Report 2008, 109 countries or territories were malaria-prone in 2006, placing 3.3 billion people at risk of malaria transmission. Every year, several 100 million cases of malaria occur, and cause an estimated death toll of over a million, over 90% of it in Africa. However, much of the South Asian population remains an area of active malaria transmission and houses a vast population that is at risk (WHO 2008). Therefore, studying the past trends in malaria occurrence in South Asia[1] and learning the lessons of prevention and control is exceedingly important to future efforts at malaria control.

Malaria in the Twentieth Century

At the dawn of the twentieth century, malaria mortality rates were very high—194 deaths per 100,000 persons; the rate for sub-Saharan Africa was much higher, but if left out of the accounting, most global deaths due to malaria were in the tropical regions of Asia and Pacific (Fig. 1.2). Soon after the discovery of the cause of malaria, drugs (mainly quinine) were identified for its cure. The result was a slight decline in global malaria mortality to 174 per 100,000 by 1930. The most remarkable decline to 48 deaths per 100,000 persons in 1950 occurred after the Second World War as a result of national malaria control drives supported by the WHO, particularly in many of the affected South and Southeast Asian countries. By 1970, global malaria mortality fell even more sharply to 16 deaths per 100,000 persons, although mortality rates in sub-Saharan Africa continued to be as high as 107 per 100,000 (WHO 1999a) (Fig. 1.2).

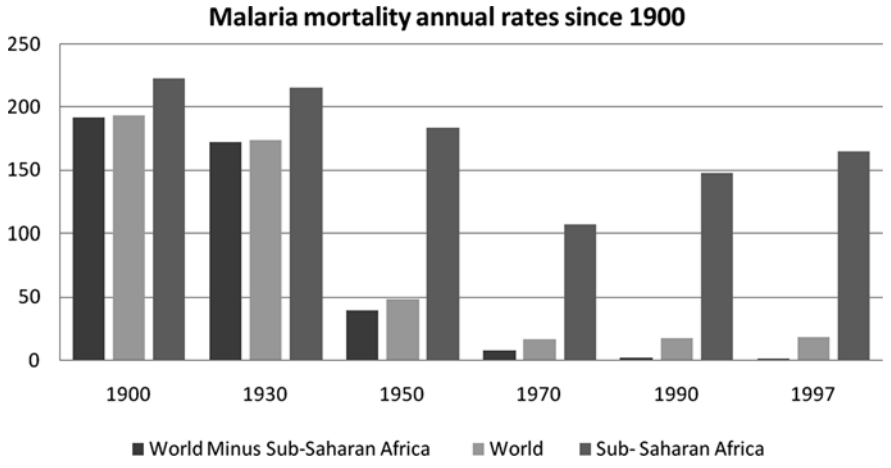


Fig. 1.2 Annual rates of malaria mortality for the world, sub-Saharan Africa (SSA), and world minus sub-Saharan Africa: 1900–1997
Source: WHO 1999a.

However, a resurgence of the disease in Africa and Asia in subsequent years was reflected in the consistent increase in mortality rates over the next few years, marked with periodic recessions, a trend continuing until the last decade of the century (see WHO 1996; WHO 1999a). By 1995, malaria had become one of the main infectious diseases of the world, with mortalities ranging from 1.5 to 2.7 million persons worldwide. At this time, only three other infectious diseases, acute lower respiratory infection (ALRI), tuberculosis, and diarrhea killed more people than malaria. However, in terms of new incidence of the disease, malaria ranked second only to diarrhea. In fact, the 1996 World Health Report affirmed that between a quarter-billion and a half-billion people were recipients of new malaria infection each year. Further, compared to all insect-borne diseases, it remained the worst killer (WHO 1996).

Malaria mortality fell slightly to just over 1.1 million in 1998, with 273 million new infections (WHO 1999a and b). However, malaria kills a much smaller proportion of people compared to its new incidence of infection. For example, in the 1980s and early 1990s, AIDS compared badly in terms of the new incidence and death relationship. Almost every case of AIDS was likely to result in death, albeit after a prolonged period of time; today, the continuous use of appropriate anti-retroviral drugs can significantly prolong the life span of an HIV-infected person. In the case of malaria, only one death results for every 270 new infections.

The reasons relatively fewer people die of malaria compared to new infection are as follows:

1. In general, the disease is treatable and curable with modern medicine. The research for curative medicine had developed extensively during the twentieth century. The treatment and cure of malaria started with quinine and continued as such until the 1930s and the early 1940s. More sophisticated chemotherapeutic drugs such as chloroquine phosphate, sulfadoxine–pyrimethamine, and quinine sulphate were developed over time, and used widely in the affected areas, at least until the phenomenon of drug resistance became an issue.
2. Once infected, a population develops resistance to malaria so that reinfection is staggered and less virulent in a previously affected area.
3. After the Second World War, the network of treatment and prevention of malaria in affected countries was developed extensively, mostly due to the significant role of the WHO. Through this network, malaria was kept controlled to a great degree even in endemic countries, until lack of political will resulted in a degeneration of this system and additional problems such as vector resistance to DDT and drug resistance of the *plasmodia* became serious stumbling blocks in the fight against malaria.

At the close of the twentieth century in 1998, Africa saw 961,000 fatalities due to malaria. Because of lack of resistance and inadequate medical care, children 0–4 years old are the most vulnerable in Africa, with almost 78% of deaths by malaria occurring in this age group. In the same year, malaria caused 73,000 deaths in South and Southeast Asia (SEA), of which 20,000 occurred in India alone. Here, it is the

5–14 and 15–44 age groups that account for most of the deaths by malaria, about 70% of total mortality (WHO 1999b). Therefore, in SEA, more adults are affected with malaria than are children. In Africa, the reverse is true, where more children are affected than are adults.

Africa, SEA, and rest of the world show some slight variations in malaria mortality rates by sex and age group: a slightly larger proportion of males die of malaria in the 0–4 age group, but in the 15–44 age group in Africa and SEA, a slightly higher proportion of females are affected by the disease (WHO 1999b), possibly due to the high vulnerability of pregnant women to the disease (Fig. 1.3).

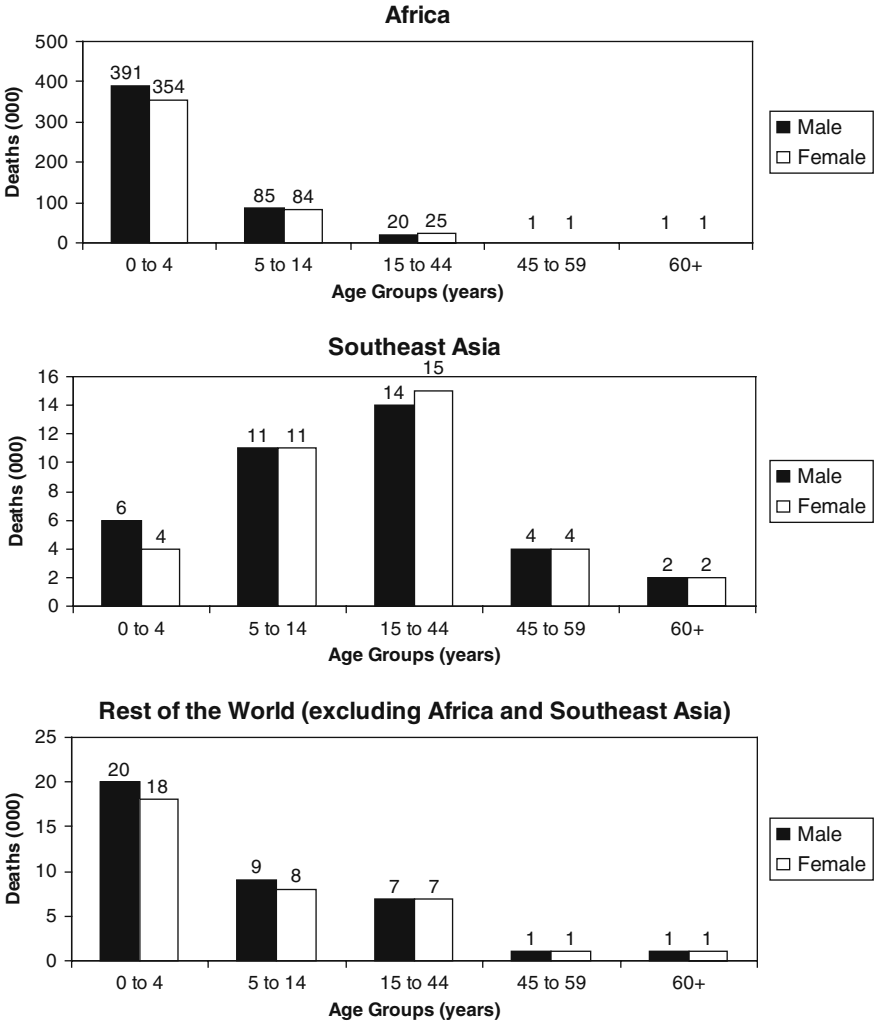


Fig. 1.3 Malaria mortality by gender and age for Africa, Southeast Asia, and rest of the world, 1998
Source: World Health Organization (1999b).

In terms of morbidity, there is a slight change in the pattern in Africa. Malaria incidence is almost equal in the 0–4 and 15–44 age groups (approximately 40 and 41%, respectively). In SEA, the respective figures are 13% (0–4 age group) and 46% (15–44 age group). These numbers reflect the delicate vulnerability of young children as well as the productive age groups in Africa and the high susceptibility of the latter in SEA populations to malaria. Again, the female population in the reproductive age groups of both regions display slightly higher morbidity patterns (Fig. 1.4).

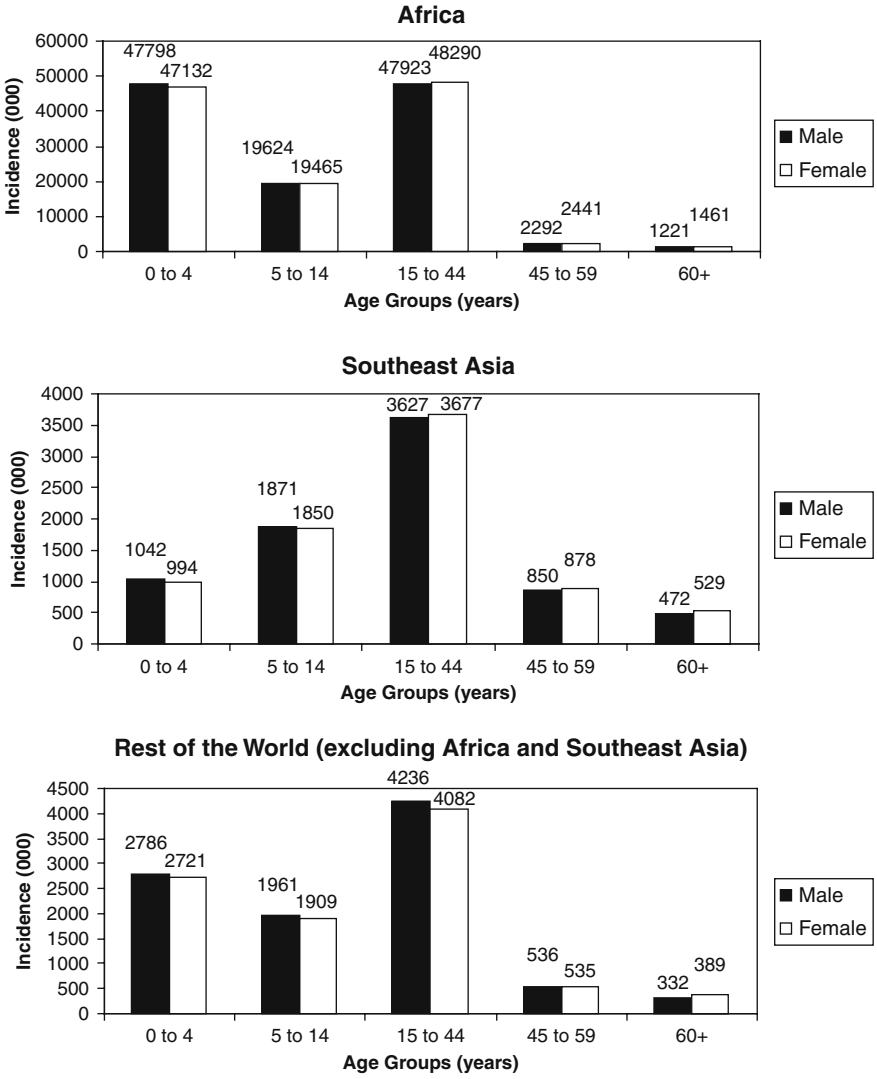


Fig. 1.4 Malaria morbidity by gender and age for Africa, Southeast Asia, and rest of the world, 1998
Source: World Health Organization (1999b).

Malaria continues to be a disease of the tropics. By the end of the twentieth century, it was endemic to 91 countries across the globe, including all seven comprising the South Asian region, although almost 90% of all the malaria cases in the world occurred in Africa alone (WHO 1996, 47). Referring again to the global geographic spread of malaria given in Fig. 1.1, it is evident that countries lying within tropical zones and those that also have limited financial resources are most susceptible to this disease. Globally, both malarial mortality and morbidity have declined over the years, but fluctuations are common. Through these cycles of resurgence and remissions, the threat of malaria as a dreaded disease remains a real one. Extensive and intensive efforts are still required to keep this disease at bay, and to further reduce its impact until an effective vaccine can be found.

Twenty-First Century Concerns

The WHO is optimistic about the organization and tools that have been developed for the control and eradication of malaria:

> Malaria control in the Twenty-First century will be approached through strengthened health systems, working closely with local communities to identify and tackle the specific problems of the area. An impressive array of tools for preventive and effective treatment is already available. Big inroads can be made into malaria morbidity and mortality . . . Even with growing resistance, an estimated 20% reduction in child deaths in Africa could be achieved if health systems were funded, organized and managed to bring today's knowledge and techniques within the reach of whole populations. (WHO 1999a, p. 59)

At the same time, the WHO also cautions that the ". . . state of the health system in most poor countries is itself a contributor to the scale of the malaria problem. . ." (WHO 1999a, p. 59), because such developing countries have many other urgent problems to resolve, and their limited financial ability prevents them from allocating necessary finances for malaria control or even for basic hygiene and health measures. There is no doubt that ". . . Applying available knowledge is a prerequisite to future progress." (WHO 1999a, p. 59). In the 10 years since this report expressed concern over the malaria situation, much has taken place in terms of changes in patterns of occurrence, diffusion, methods of prophylaxis, and cure. These are all discussed in Chapter 10.

Of additional concern today is the phenomenon of global climate change. At the 2007 annual assembly of the WHO held in Geneva, health experts warned that climate change, specifically, global warming, was already impacting patterns of disease occurrence, particularly parasitic diseases such as malaria that respond to shifts in climatic characteristics (MacInnes 2007). The Intergovernmental Panel on Climate Change (IPCC) asserted in its Fourth Assessment Report that climate change plays an important role in the spatial and temporal distribution of malaria (IPCC 2007). Over the last two decades, an increasing number of studies have proposed that vector-borne diseases are particularly prone to shifts in spatial patterns and intensities of occurrence due to changes in climate and weather (see Arrow et al. 2004; Epstein 2002). Vectors such as mosquitoes are highly responsive to climate

change such as global warming, which can cause mosquito-borne diseases such as malaria to occur at higher altitudes and latitudes than before. Intensity of occurrence is also affected due to changes in climate that bring about extreme weather conditions (Epstein 2002). In fact, certain shifts in patterns of the malaria vector and *plasmodia* have already been observed in countries of Asia, Africa, and South America, with the disease occurring at much higher altitudes than before (Akhtar 2007). Further, a systematic review of studies of the El Nino Southern Oscillation (ENSO) and malaria concluded that the impact of El Nino on the risk of malaria epidemics is well established in respect of southern Asia (Akhtar and McMichael 1996) and South America (Kovats et al. 2003).

South Asia has been experiencing the effects of global warming as well. Low-lying flood-prone areas, the Himalayan ice cap, large deserts, and coastal urban areas are all at risk for causing greater malaria transmission because of various mechanisms of climate change (MacInnis 2007). For instance, global warming would cause melting of the Himalayan snow cover, increasing the volume of the snow-fed rivers running through the flood plains of South Asia, and thus increasing the area of flood-prone regions. This in turn would create larger and more extended habitats for mosquito breeding, leading to an increase in areas experiencing malaria transmission. This situation is projected to continue until 2035. Thereafter, a saturation point would be reached when global climate changes would have melted Himalayan and Tibetan snowfields to the maximum capacity possible under those climatic conditions. This would be followed by a period of drought causing lesser volumes of flow in the snow-fed rivers and drying up of former flood plains, leaving isolated pools of water that would be ideal grounds for mosquito breeding (Dutt 2008).

Given the high level of complexity of the causal and control variables of the disease, Reiter et al. (2004) propose caution regarding dire predictions about how climate change would affect malaria spread and transmission. However, there is still need for forward thinking and strategic planning—the WHO's director for public health and environment, Dr. Maria Neira, suggested that climate change would engender a greater impact on the population than simply environmental and economic costs, implying that health, particularly changes in malaria occurrence, would be a matter of particular concern. According to her, it is time that decision makers focus on health-related emergency preparedness measures such as efficient and quick distribution of bed nets and prophylactics (MacInnes 2007).

Nevertheless, the importance of non-climatic factors, including socio-economic development, immunity and drug resistance in determining infection and infection outcomes cannot be ignored. Further, financial constraints of developing countries remain a bottleneck in the path toward malaria control, one that can only be removed by necessary additional aid from the more affluent countries. According to the WHO, poverty, population growth, migration, industrialization, resource shortages, and drug resistance of the malaria parasite are seen as major obstructions to malaria control. Recognizing that a vaccine will not be a reality in the near future, WHO's global malaria strategy at the end of the twentieth century emphasized prophylaxis and control through provision of early diagnosis and prompt treatment,

vector control, epidemic prevention through early trend analyses, and strengthening of local public health and sanitation infrastructures (WHO 1996, 47). The concluding chapter elaborates on the WHO's latest efforts to combat malaria as laid out in its Roll Back Malaria Campaign that was launched in 1998. The launch of the Malaria Atlas Project (MAP) in March 2009 also gives hope that this detailed mapping of malaria risk areas will be able to better guide policy and health planning efforts (Hay et al. 2009).

What Is to Follow: An Overview of the Chapters

The twentieth century may not have seen the conquest of malaria, but it saw many developments in its cure and control. It also faced a great many realities regarding the disease and its occurrence, as well as the breaking of many myths surrounding it. The greatest myth proved to be regarding malaria eradication in a consistently endemic environment such as that of South Asia. The hope of a permanent cure for malaria through the development of an effective vaccine has constantly been dashed by a *plasmodium* that continuously mutates to escape being pinned by a vaccine formulation that would render it harmless. Even effective malaria control through the use of curative and prophylactic drugs and vector management is often faced with the harsh realities of the *plasmodium's* resistance to many drugs and the vector's hardiness against most common pesticides.

South Asia has had to deal with the realities of economic and political contexts within which malaria eradication programs took place. It became apparent that such eradication would remain a myth if the political-economic realities of low resources and lack of political will were not addressed. This book presents these myths and realities regarding malaria occurrence in the upcoming chapters for five of the seven nations comprising South Asia. The situations in the other two nations of Bhutan and Maldives are addressed in the concluding chapter.

In the chapters ahead, the cycle of malaria occurrence, near eradication, resurgence, and subsequent control and preventive measures in South Asia are discussed from various perspectives. Also provided are detailed analyses of the causes and circumstances that engendered malaria resurgence, as well as identification of post-resurgence characteristics. Based on the above it has been postulated in Chapter 9 that the disease dynamics of malaria follow two patterns: cycles of resistance and cycles of regional occurrence. Further, each chapter also considers the prospect of malaria eradication in the context of the region to which the chapter is dedicated. Below is a brief description of the contents of the following chapters.

Chapter 2 and 3 focus on the island nation of Sri Lanka. Chapter 2 by Ashok Dutt, Hiran Dutta, and Clifford Parera attempts to empirically prove that "environmental determinism" does not play as large a part as expected in the occurrence of malaria in Sri Lanka because of the significant role of human intervention through prevention and public health methods. The chapter details the resurgence of malaria that

took place in the late 1960s through the 1970s, peaking in 1975, and spreading from two foci: Northcentral and Southeast Sri Lanka. The pattern of resurgence recorded from 1972 to 1976 reveals the Wet Zone to be less significant as regards malaria occurrence. The resurgence is thought to be the result of complacency of control officers and field workers, neglect of mosquito-breeding areas, drug resistance of the *plasmodium*, and lack of financial and infrastructural resources. The authors maintain that prevention is the only effective control measure against malaria in a country where the ecology is favorable to the disease, resources are low, and population contact is vast.

Chapter 3 by Gisela Peters investigates the reasons behind the spread of malaria in Sri Lanka and the nature of its diffusion over the country. This detailed geomedical analysis attempts to develop policy measures to counter the ecological elements that cause the spread of malaria. It supports the previous chapter's observation that the ecology of the Dry Zone is more prone to the disease and is in fact, endemic. Malaria in Sri Lanka has high seasonal variability, and its occurrence and spread follow a distinct pattern. This pattern consists of five foci/centers (north, south, west, east, and interior), and four paths of transmission (northward, southward, eastward, and westward). The south center is the most intense, but not in terms of spread; the north center is next, spreading to the interior, west, and east. The north axis is the most important in terms of influence, followed by the west axis. The other axes are less significant and have a seasonal activation pattern. The author finds that factors such as climate, topography, geology, water reservoir systems, and cultural traits of the population all contribute to or inhibit malaria occurrence and spread. It is suggested that river development projects can be used as a tool for malaria control by bringing about planned development and awareness. However, careless implementation may aggravate the situation by providing areas that are conducive to vector breeding, such as waterlogged spots and construction sites. Other anti-malarial strategies proposed are prophylactic measures (spraying of houses and breeding areas with appropriate insecticides and larvicides, respectively), filling in of small water bodies, planned irrigation and agriculture, monitoring of climatic and other changes to predict outbreaks, and awareness programs.

Chapter 4 by Bishnu Dev Pant focuses on the resurgence of malaria in Nepal in the 1970s and the early 1980s. This chapter traces Nepal's pre-resurgence anti-malarial strategy and discusses characteristics and causes of the resurgence. The comparative results of Annual Parasite Indices (APIs) for 1976 and 1982 reveal an overall increase in malaria incidence. More districts fell in the "very high" and "medium" API categories. Districts located on the western border with India and falling in the "high" category in 1976 fell into the "very high" category in 1982, pointing at migration–diffusion as a major causative factor. Districts with inaccessible hilly terrain also showed an increase in malaria incidence. Pant attempts to understand associations between API and aspects of population density, agricultural density, rainfall, and irrigation intensity. Only population density showed a significant correlation with API. Pant calls for inter-governmental agency coordination for appropriate planning of control and prevention measures.

Chapters 5 and 6 focus on Bangladesh. Chapter 5 by Ashok Dutt, Ishrat Islam, and Adrien Humphreys traces the occurrence of malaria in Bangladesh from the late 1940s to the early years of the 1990s, focusing on the resurgence that started in 1972 that waned considerably by 1987, but gave way to a new post-resurgence period soon after. During this period, the disease diffused from east to west because the notorious vector *A. balabacensis*, which breeds in forested and rainy environments, had taken firm hold in Southeastern Bangladesh. This area became the main nucleus of malaria diffusion.

Chapter 6 by Maudood Elahi and Sabiha Sultana aims to examine the conditions associated with the resurgence of malaria in Bangladesh, its status in the 1990s, spatial trend of resurgence, and the possibility of research intervention in malarial geography. The authors divide the country into high-, medium-, and low-risk zones based on epidemiology, geo-ecology, and infrastructural intervention. The high-risk zone covers the east, northeast, and southeast parts of the country and has ideal physical and infrastructural features for the start and spread of malaria. It accounts for 10% of the malaria affected population. The medium-risk zone lies west of the former and includes 12% of the affected population. The traditionally low-risk zone accounts for 78% of the affected population and lies in the flood plains, where running water has typically flushed out most vector breeding areas. However, the surface hydrology has changed due to human intervention, making this area an excellent breeding ground for the malaria vector. The authors suggest that action against malaria be broadened to cover all zones, and an inter-disciplinary approach marrying regional studies, technical advancements, and geomedical research be developed to combat and eradicate the disease.

Chapter 7 by Iqtidar Zaidi and Jamil Kazmi traces the spatial pattern of malaria in Pakistan context of the "game theory" as defined by the late Peter Gould. The players here are the course of nature and human intervention. The period from 1972–1973 to 1978–1979 completes one round of this game, reflecting the malaria peak of 1972 and its trough in 1979. The authors compare the spatial variations of the disease among 37 malaria control zones in an effort to evaluate the performance of local control efforts, hoping to enable the definition of more effective strategies. The authors find that the waxing and waning of Pakistan's malaria rates are related to flooding patterns. The forested wetlands, swamps, and sloughs make the entire country an excellent mosquito breeding ground. Three rural vectors are present, while *A. stephensi* is the major urban malarial vector breeding in areas of rapid urbanization that have no proper sanitary infrastructure. It is pointed out that Pakistan's health planners made two mistaken assumptions: (i) like the WHO at the time, they believed that since malaria vectors could be controlled, the disease could be eradicated and (ii) there was a belief that malaria was primarily a rural affliction, therefore spraying DDT in agricultural areas would be an effective low-cost eradication method. The variety of problems encountered and mistakes made in Pakistan's malaria control efforts leave the authors unable to prove that malaria cannot be completely eradicated. However, they feel eradication is an unrealistic goal, since the disease is still prevalent in so many countries despite great efforts. The authors suggest aiming for the "bearable threshold"

instead, which is a low malaria incidence rate of 4 cases per 10,000 people (40 per 100,000 people). If the incidence is limited to this point, the resurgence of malaria is considered unlikely, given the careful observance of relevant public health standards.

Chapters 8 and 9 focus on the resurgence of malaria in urban India, wherein the latter chapter is, in essence, a continuation of the former. In Chapter 8, Rais Akhtar, Ashok Dutt, and Vandana Wadhwa use the history of malaria and health planning efforts in India as a backdrop for a time point comparison between the years 1978 and 1993. Spatio-temporal patterns of urban malaria incidence are mapped and described for these points in time. The authors found that in 1978, the nonendemic Northwest was the focus of malaria intensity, with a few isolated cases in Southeast India. This was due to the establishment of *A. stephensi* as a major urban vector, urban development activity in nearby rural areas that provided breeding areas, and the lack of malaria resistance in the population of this nonendemic area. In 1993, the centers of malaria intensity had reverted back to the endemic centers of West, Southeast, and Northeast India since the population here had lost its resistance to malaria, and anti-malarial measures were not being applied to the desired extent. However, a geographic spread in malaria incidence was noticeable in the Northwest, particularly along the new urban and industrial corridors of development, which provide suitable breeding grounds for the urban malaria vector.

Chapter 9 by Vandana Wadhwa, Rais Akhtar, and Ashok Dutt provides an update on the scenario of urban malaria in India, picking up from the previous study in the year 1994, and leading up until 1997, the year for which the latest data of the kind were available for analysis. This time, the backdrop for the study is urban ecology, using this as a possible explanation for malaria occurrence and as a guideline for future policy decisions. The 1994 scenario is still similar to the one in 1993, with the endemic southeast, west, and northeast as centers of malaria intensity. By 1997, the situation reverts to the one found in 1978, with the focus of malaria in the Northwest as the population here loses its earlier malaria resistance. Thus, the authors conclude that malaria occurs in cyclic form. The two studies put together exhibit one entire cycle of regional occurrence and two cycles of resistance. The cycles of regional occurrence begin in the nonendemic northwestern region, move to the traditional endemic centers at its midpoint, and finally come back full circle to the Northwest. The two cycles of malaria resistance occur within a 19-year period covering two cycles spanning roughly 10 years each. Each cycle of regional occurrence seems to encompass two cycles of malaria resistance by the population. However, despite the cyclic recurrence of the disease, the authors find that the encouraging trend visible here is the consistent drop in malaria intensity over time.

Chapter 10, the concluding chapter by Vandana Wadhwa and Ashok Dutt, synthesizes the preceding chapters using the role of physical and human cultural environments as explanatory factors in the trends of malaria occurrence, resurgence, and vicissitudes. This last chapter updates the malaria scenario in South Asia by briefly summarizing present conditions and noting the malaria situation in Bhutan and Maldives, two countries not represented in the chapters of this book. It also consolidates current knowledge of eradication efforts through vaccine

development and genetic engineering and comprehensively reports on the bastions of malaria control—vector management and disease cure and prophylaxis. Finally, the authors develop and present a descriptive model of malaria as based on historical changes and current paradigms in the scientific progress in understanding its causes, prevention, treatment, and cure.

Notes

1. It should be noted at this point that for the purposes of this book, we define "South Asia" as comprising the nations of Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka, congruent to Dutt and Geib's (1987) definition. Narain (2008) and all other World Health Organization literature refer to "Southeast Asia Region" (also referred to as "South and Southeast Asia Region") that is much broader in scope, encompassing not just countries of the Indian subcontinent, but also nations southeast of it, while counting Pakistan in the eastern Mediterranean region. However disaggregated data by country were not consistently available to present charts and graphs for South Asia as per our definition in the later section on "Trends in Occurrence of Malaria," so the WHO definitions of South and Southeast Asia have been used to provide a general picture of malaria occurrence in that region.
2. On 20 August 1897, Ronald Ross was able to show the mechanism of malaria transmission in a hospital in Secunderabad (AP), when he discovered öocysts lodged in the stomach wall of the *Anopheles Stephensi* mosquito. In celebration of 100 years of this discovery, the Second Global Meet on Parasitic Diseases (special focus on malaria) was held in Secunderabad, and Minister's Road as well as the Fever Hospital in neighboring Hyderabad city were renamed in his honor. Many years earlier, his continued work in Kolkata was also honored when the street near the former Presidency Hospital located adjacent to the Victoria Memorial where Roland Ross conducted the historical experiment on malaria transmission to the host was renamed after him (see "Malaria—Hundred years after the great discovery" at http://www.ias.ac.in/jarch/currsci/74/00000103.pdf (accessed 18 September 2009); CDC 2004b; renaming of street in Kolkata recounted by second author through personal knowledge and observation).
3. These sets of up to 150 genes were seen to be so variable that the family of genes was dubbed *var* (for variation) by one of the NIAID teams led by Dr. Thomas Wellems.
4. Pre-erythrocytic stage refers to the phase of the malarial cycle that occurs before the *merozoites* enter the RBCs (refer the malarial cycle). Therefore, a pre-erythrocytic stage vaccine would target either the *sporozoites* or the incubation stage in the liver.

References

Akhtar, R. (2007), Health and climate in Kashmir, *Tiempo*, 63(April issue), 19–21.

Akhtar, R. and McMichael, A.J. (1996), Rainfall and malaria outbreaks in western Rajasthan, *Lancet*, 348 (9039): 1457–1458.

Alonso, P.L., Sacarlal, J., Aponte, J.J., Leach, A., Macete, E., et al. (2005), Duration of protection with RTS,S/AS02A malaria vaccine in prevention of Plasmodium falciparum disease in Mozambican children: single-blind extended follow-up of a randomised controlled trial, *Lancet*, 366(9502): 2012–2018.

Arrow, K., Panosian, C.B. and Gelband, H. (eds) (2004), *Saving lives, buying time: Economics of malaria drugs in an age of resistance*, Committee on the Economics of Antimalarial Drugs, Board on Global Health, Washington DC: The National Academies Press. Retrieved June 5, 2006 from National Academies Press database.

BBC News, (2004), *Hopes of a malaria vaccine by 2010*, 15 October. Retrieved July 13, 2007 from BBC website http://news.bbc.co.uk/2/hi/health/3742876.stm

Bojang, K.A., Milligan, P.J.M., Pinder, M., Vigneron, L., Allouecheе, A., et al. (2001), Efficacy of RTS,S/AS02 malaria vaccine against *Plasmodium falciparum* infection in semi-immune adult men in The Gambia: a randomised trial, *Lancet*, 358(9297): 1927–1934.

Carter, R. and Mendis, K.N. (2002), Evolutionary and historical aspects of the burden of malaria, *Clin Microbiol Rev*, 15(4): 564–594. Retrieved July 13, 2007, from CMR database.

Cartwright, F. (1972), *Disease and History*, New York: Dorset Press.

CDC (2004), *The history of malaria, an ancient disease*. Retrieved June 6, 2006, from CDC website, http://www.cdc.gov/malaria/history/

CDC (2008), *Malaria: Anopheles Mosquitoes*, Retrieved May 20, 2009 from CDC website, http://www.cdc.gov/malaria/biology/mosquito/

Cheng, M. (2007), Malaria drugs could cut deaths in Africa, AP, March 1, 2007. Retrieved February 1, 2009 from *The Washington Post* website http://www.washingtonpost.com/wp-dyn/content/article/2007/03/01/AR2007030100173.html

Colley, B.M. (n.d.), *The history of Gilbert & Bennett Mfg. Co. 1818–2001*. Retrieved June 6, 2006, from http://www.historyofredding.com/HGgilbertbennett.htm

Curtis, C.F. and Lines, J.D. (2000), Should DDT be banned by international treaty? *Parasitol Today*, 16(3): 119–121.

D'Alessandro, U., Leach, A., Drakeley, C.J., Bennett, S., Olaleye, B.O., et al. (1995), Efficacy trial of malaria vaccine SPf66 in Gambian infants, *Lancet*, 346(8973): 462–467.

Desowitz, R. (1991), *The Malaria Capers: More Tales of Parasites and People, Research and Reality*, New York: W.W. Norton & Company.

Dutt, A. (2008), India and Nepal, in J.G. Golson and G. Philanders (eds), *Encyclopedia of Global Warming and Climate Change*, Thousand Oaks, CA: Sage Publications.

Dutt, A.K. and Dutta, H.M. (1986), Disease dynamics in South and South-east Asia with special reference to India, in R. Akhtar and A.T.A. Learmonth (eds), *Geographical Aspects of Health and Disease in India*, New Delhi: Concept Publishing Company, pp. 37–47.

Dutt, A.K. and Geib, M. (1987), *Atlas of South Asia*, Boulder, CO: Westview Press.

Dutta, H.M. and Dutt, A.K. (1978), Malaria ecology: a global perspective, *Soc Sci Med*, 12(2): 69–84.

Dutta, H.M. and Dutt, A.K. (2007), DDT, in P. Robbins (ed), *Encyclopedia of Environment and Society*, Golson and Sage Publications.

Epstein, P.R. (2002), Detecting the infectious disease consequences of climate change and extreme weather events, in W.J.M. Martens and A.J. McMichael (eds), *Environmental Change, Climate and Health: Issues and Research Methods*, Cambridge, UK: Cambridge University Press, pp. 172–196.

Finkel, M. (2007), Bedlam in the Blood: Malaria, *Natl Geo*, July: 31–67.

Gardiner, D.L., McCarthy, J.S. and Trenholme, K.R. (2005), Malaria in the post-genomics era: light at the end of the tunnel or just another train? *Postgrad Med J*, 81: 505–509. Retrieved July 13, 2007 from PMJ Online Database.

Gimnig, J.E., Kolczak, M.S., Hightower, A.W., Vulule, J.M., Schoute, E., et al. (2003), Effect of permethrin-treated bed nets on the spatial distribution of malaria vectors in western Kenya, *Am J Trop Med Hyg*, 68(4): 115–120. Retrieved July 13, 2007, from American Society of Tropical Medicine and Hygiene database.

Handwerk, B. (2006), DDT to return as weapon against malaria, experts say, *National Geographic News* August 1 http://news.nationalgeographic.com/news/2006/08/060801-ddt-malaria.html retrieved August 22, 2007.

Hay, S.I., et al. (2009), A World Malaria Map: *Plasmodium Falciparum* endemicity in 2007. *PLoS Med*, 6(6), e1000048. doi:10.1371/journal.pmed.1000048. Retrieved May 23, 2009, from Public Library of Science (PloS) database.

Hudson, L. (1995), First malaria vaccine trial results prove disappointing in Gambia, *India Abroad*, 15 September, p. 46.

IPCC. (2007), *Climate Change: Impacts, Adaptation and Vulnerability* (Chapter on Human Health), Cambridge, U.K.: Cambridge University Press.

Killeen, G.F., Smith, T.A., Ferguson, H.M., Mshinda, H., Abdulla, S., et al. (2007), Preventing childhood malaria in Africa by protecting adults from mosquitoes with Insecticide-Treated Nets, *PLoS Med*, 4(7), e229 doi:10.1371/journal.pmed.0040229. Retrieved July 14, 2007, from Public Library of Science (PloS) database.

Kovats, R.S., Bouma, M.J., Hajat, S., Worall, E. and Haines, A. (2003), El Nino and health, *Lancet*, 362 (9394): 1481–1489.

Lambert, P-H. (2003), *Malaria past and present*. Retrieved June 5, 2006, from the official website of the Nobel Foundation, http://nobelprize.org/educational_games/medicine/malaria/readmore/treatment.html

MacInnis, L. (2007), Climate change to spur allergies, ticks, malaria: U.N. *Reuters*, 22 May. Retrieved July 19, 2007, from the Reuters website, http://www.reuters.com/article/environmentNews/idUSL2235668420070523

May, J.M. (1961), *Studies in Disease Ecology*, New York: Hafner Publishing Co.

McGivering, J. (2009), Fears for new malaria drug resistance, *BBC News*, BBC World Service Cambodia, 28 May. Retrieved May 29, 2009, from the BBC World News website, http://news.bbc.co.uk/2/hi/asia-pacific/8072742.stm</misc

McPhee, S.J., Papadakis, M.A. and Tierney, Jr., L.M. (2008), *Current Medical Diagnosis and Treatment* (47th edn.). New York, Burr Hill, IL, San Francisco, United States: McGraw Hill Professional.

Narain, J.P. (2008), Malaria in the South-East Asia Region: Myth & the reality. *Indian J Med Res*, 128(1): 1–3, Retrieved January 10, 2008 from WHO/SEARO website http://www.searo.who.int/LinkFiles/Malaria_editorial_Myth&reality.pdf

Nowak, R. (1995), How the parasite disguises itself, *Science*, 269(August 11), p. 755.

NYU Medical Center/NYU School of Medicine (n.d.), *A Brief History of Malaria Vaccine Research Within the Department of Medical Parasitology*. Retrieved July 13, 2007, from NYU School of Medicine website, http://www.med.nyu.edu/parasitology/aboutus/vaccine_research.html

Packard, R.M. (2007), *The Making of a Tropical Disease: A Short History of Malaria* (Johns Hopkins Biographies of Disease), Baltimore: Johns Hopkins University Press.

Poser, C.M. and Bruyn, G.W. (1999), *An Illustrated History of Malaria*. New York: Parthenon Publishing.

Reiter, P., Thomas, C.J., Atkinson, P.M., Hay, S.I., et al. (2004), Global warming and malaria: A call for accuracy, *Lancet Infect Dis*, 4(June), p. 323.

Rogan, W.J. and Chen, A. (2005), Health risks and benefits of bis(4-chlorophenyl)-1,1, 1-trichloroethane (DDT). *Lancet*, 366(9487): 763–773.

Sallares, R. (2002), *Malaria and Rome: A History of Malaria in Ancient Rome*, New York: Oxford University Press.

Schlagenhauf, P. (2004), Malaria: From Prehistory to Present, *Infect Dis Clin North Am*, 18(2): 189–205.

Sinha, K. (2009), Drug-resistant malaria in Thailand. India next?, Times of India, 25 April 2009. Retrieved May 15, 2009 from Times of India website, http://timesofindia.indiatimes.com/India/Drug-resistant-malaria-in-Thailand-India-next/articleshow/4445605.cms

Taylor, J.M. (2006), Africa Launches DDT Attack against malaria, *Environment News, 1* July 2006. Retrieved August 17, 2006 from Heartland Institute website, http://www.heartland.org/Article.cfm?artId=19327.

Thacker, J.R.M. (2002), *An Introduction to Arthropod Pest Control*, Cambridge, UK: Cambridge University Press.

Wallis, C. (1984), Combating an ancient enemy, August 13. Retrieved April 8, 2008 from *Time* magazine website http://www.time.com/time/magazine/article/0,9171,926775–2,00.html

Ware, G.W. and Whitacre, D.M. (2004), *The Pesticide Book*, 6th edn, Willoughby, OH: MeisterPro Information Resources.

White, N.J. (2006), Modelling malaria control, *PLoS Med*, 3(5), e111 doi:10.1371/journal.pmed.0030111. Retrieved July 07 2007, from Public Library of Science (PloS) database.

WHO (1996), *The World Health Report 1996: Fighting Disease, Fostering Development*, Geneva: World Health Organization.

WHO (1999a), *The World Health Report 1999: Making a Difference*, Geneva World Health Organization.

WHO (1999b), *The World Health Report 1999*: *Statistical Annex*. Retrieved April 5, 2005, from World Health Organization website, http://www.who.int/whr/1999/en/whr99_annex_en.pdf

WHO (2005), *Frequently asked questions on DDT use for disease vector control*. Retrieved June 4, 2006, from World Health Organization website http://www.who.int/malaria/docs/FAQonDDT.pdf

WHO (2006), *Indoor residual spraying: Use of indoor residual spraying for scaling up global malaria control and elimination*, World Health Organization Position Paper. Retrieved June 18, 2007, from WHO website http://malaria.who.int/docs/IRS-position.pdf

WHO (2008), *World Malaria Report 2008*. Retrieved June 25, 2009 from WHO website http://apps.who.int/malaria/wmr2008/malaria2008.pdf

WHO (n.d.) *Initiative for Vaccine Research: Infectious diseases, malaria*. Retrieved, July 18, 2007, from World Health Organization website http://www.who.int/vaccine_research/diseases/soa_parasitic/en/index4.html

Wichman, O.,et al. (2004), Malarone treatment failure not associated with previously described mutations in the cytochrome b gene. *Malar J*, 3(14): doi 10.1186/1475-2875-3-14. Retrieved June 23, 2007 from Biomed Central website http://www.malariajournal.com/content/3/1/14

Chapter 2
Resurgence of Malaria in Sri Lanka in the 1970s

Ashok K. Dutt, Hiran M. Dutta, and Clifford Parera

Abstract Environmental conditions and malaria occurrence have a strong relation with each other in Sri Lanka. The wet zone in southwestern Sri Lanka is relatively malaria free since water logging is minimal, partly because of the steep slopes. Using 1972–1976 data on malaria occurrence, this study reveals that malaria did not establish a foothold in the wet zone but Sri Lanka's dry zone was affected considerably. Like in other countries of South Asia, it seems that in the case of Sri Lanka, malaria elimination seems a high probability with preventive and curative measures. However, the recurring multiple human and environmental factors causing malaria incidence make it likely that malaria eradication will only be possible after discovery of vaccines.

Keywords Sri Lanka · Malaria eradication · Dry and wet zones · Vaccines

Malaria occurrence and environmental determinism are closely related in many respects. Environmental determinism dominated geographic thought during the first third of the 20th century. It postulated that the pattern of human activity is heavily dependent on elements of the natural environment, such as physiography, climate, soils, biota, and geology. Accordingly, environmental determinists patterned the spatial global occurrence of diseases based on physical factors. Jacques May elaborated on the concept of environmental determinism and called it the "ecology of malaria" consisting of three basic factors: agent (*Plasmodium*), host (humans), and vector (female *Anopheles* mosquito), "each of which can survive in a variety of locations and under a variety of circumstances." (May 1961, 161). By extension, each of these is affected by the surrounding physical and cultural environments (see Dutt and Dutta 1985).

A.K. Dutt (✉)
Professor Emeritus of Geography, Planning and Urban Studies, University of Akron, Akron, OH, USA
e-mail: dutt@uakron.edu

R. Akhtar et al. (eds.), *Malaria in South Asia*, Advances in Asian Human-Environmental Research 1, DOI 10.1007/978-90-481-3358-1_2,

This empirical study proves that environmental factors did not influence the spatial patterns of malaria in Sri Lanka to the extent projected by the environmental determinist viewpoint. This is because, starting in 1946, anti-malaria campaigns were launched using DDT spraying and other public health methods in order to reverse the conducive conditions presented by the environment to the disease (Harrison 1978, 229). Thus, a change was brought about in the "variety of circumstances" that was clearly reflected in the decline of malaria incidence over the next decade. In 1945–1946, the rate of malaria mortality in Sri Lanka was 20.3 cases per 1,000 people, which declined to 14.3 per 1,000 people in 1947 after the initiation of the anti-malaria campaign; in 1956 the incidence fell even lower and the mortality rate fell close to a phenomenal low of zero (Harrison 1978, 203).

Physical Factors Affecting Malaria

Sri Lanka, an island nation with a population of 17.6 million in 1992 (approximately 20.5 million as of 2007), lies at the northern edge of the equatorial zone, with an area of 65,610 sq km (925,332 sq mi) that extends from 6°N to 10°N latitude. Based on the mean annual rainfall, the country can be divided into two zones: dry and wet (Fig. 2.1). Each zone has distinctive characteristics; the dry zone is endemically malarial, the wet zone is generally malaria free, but severe epidemics occur occasionally. In the following discussion, malarial characteristics are detailed by zone of occurrence.

A great part of the country lies in the dry zone (north and west Sri Lanka—regions III, IV, V, and VI: for detailed map, see Fig. 3.9), which receives less than 3 in. (7.6 cm) of rainfall per month during the period spanning February to September (Farmer 1967, 792). This amount of monthly rainfall is considered low in equatorial climates where evapotranspiration is very high, because evaporation negates the effects of precipitation. However, most of the dry zone's weather stations record more than 10 inches (25.4 cm) of rainfall per month for the period from October to December. Therefore, the climate alternates between a short rainy season (3–4 months) caused by a strong northwest monsoon, followed by a long dry season of 8–9 months, which indicates the weakness of the southwest monsoon. This seasonal variation, coupled with the irregularity of effective rainfall, high year-round temperatures (mean monthly temperature above 75°F or 25°C), high relative humidity (above 60%), and undulating terrain provides prime breeding grounds for the *Anopheles culicifacies* mosquito.

A. culicifacies, which is the principal transmitter of the *plasmodium* in Sri Lanka, breeds in shallow, stagnant water. Therefore, the depleted lowland streams of the dry zone provide excellent breeding areas for mosquitoes (Spate and Learmonth 1967). Temperature and humidity are critical factors affecting the longevity of these mosquitoes. Temperatures ranging between 77°F (25°C) and 86°F (30°C), and relative humidity between 60 and 80% present an ideal environment for the vector's maximum longevity (Service 1976). Therefore, natural environmental determinants create endemic malarial conditions in the dry zone.

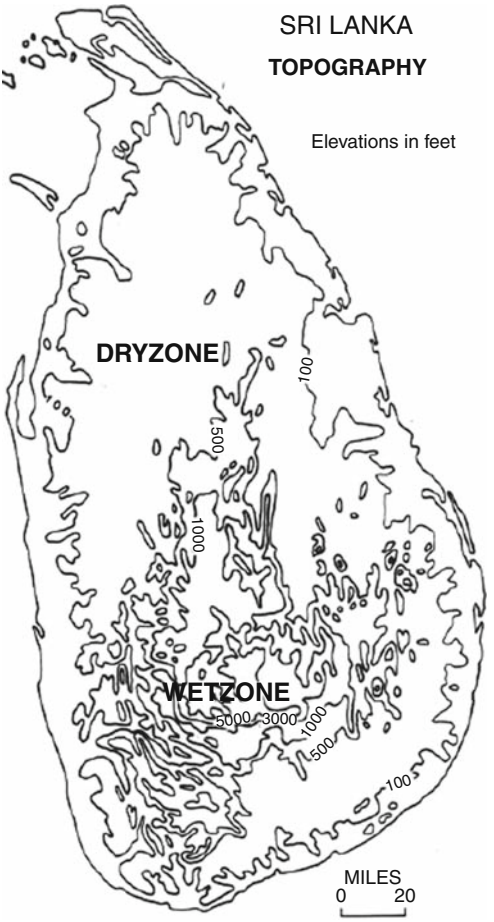


Fig. 2.1 Map showing the dry and wet zones and contour lines: Sri Lanka

The wet zone lies in the southwestern region of Sri Lanka and receives more than 75 in. (190.5 cm) of rain annually, with peak precipitation occurring in the months of May and October. The lowest average rainfall for any month never falls below 3 inches (7.6 cm). The steep slopes of this zone's topography do not allow for any water accumulation (Fig. 2.1), therefore breeding grounds for malaria-causing mosquitoes are rare. Moreover, it is possible that ecological competition causes withdrawal of malaria-causing mosquitoes due to dominance of other species and genera of mosquitoes in the wet zone. In other words, malaria-causing mosquitoes possibly give in, whereas other mosquitoes find the environment of the wet zone more conducive to breeding. Thus, this area remains malaria-free.

The well-drained topography of the wet zone certainly helps in creating a malaria-free environment, but occasional variations in climatic conditions cause droughts, creating accumulations of standing water along streams. These then

provide breeding grounds for *A. culicifacies*. For instance, following a drought, a severe malaria epidemic occurred in the so-called "malaria-free" wet zone in 1934–1935. When the area was sprayed with DDT following the 1950 drought, no epidemic reoccurred. "At last, it seemed, man and not nature had the upper hand" (Spate and Learmonth 1967, 795). Therefore, an environmentally determined (and occasional) malaria epidemic in Sri Lanka's wet zone was avoided, negating the impact of environmental determinism.

At one time, malaria was thought to be on the verge of eradication in all of Sri Lanka. Malaria control programs began in 1945–1946, using DDT for vector killing. By 1956, overall malaria incidence had declined from 3,000,000 to a mere 7300, with a malaria mortality rate of near zero (Harrison 1978, 203). By the early 1960s only 18 cases were reported in the duration of a whole year (Wallis 1984). Malaria was supposedly "eradicated," and the World Health Organization (WHO) hailed Sri Lanka as a model of success for worldwide malaria control.

A similar scenario occurred in the neighboring countries of India and Bangladesh. The incidence of malaria in India dropped from 75 million cases in 1947 to only 100,185 cases in 1965 (Akhtar and Learmonth 1977). In 1947, deaths caused by malaria in India totaled 1,066,269, while this number was reduced to only a few by the mid-1960s. In Bangladesh, malaria was a major cause of death, before the introduction of anti-malaria campaigns in 1961, when approximately 15% of all deaths in Bangladesh were caused by this disease. After a decade-long anti-malaria campaign, malaria cases dropped to a low of 10.8 per 100,000 in 1968 and 4.22 per 100,000 in 1971 (Paul 1984). However, while India experienced the lowest number of reported malaria cases in the mid-1960s, and Bangladesh's malaria problem declined significantly in the early 1970s, Sri Lanka remained the first nation in South Asia to experience a sharp decline in the incidence of malaria almost to the point of eradication.

Resurgence of Malaria

Worldwide, the reported cases of malaria increased by 231% between 1972 and 1976, while South and Southeast Asia's reported number of cases increased by a much greater rate of 340% (WHO 1978, 226). A significant resurgence of malaria began in Sri Lanka during the late 1960s, a phenomenon that became apparent in India and Bangladesh only in the 1970s (Paul 1984; Dutt et al. 1980). Sri Lanka's recorded number of malaria cases peaked from 122,958 cases in 1972 to 400,777 in 1975, an increase of 229.96% (Figs. 2.2, 2.3, and 2.4).

In Bangladesh, resurgence of malaria became evident in 1976 when reported cases rose from 25 per 100,000 in 1972 to 60 per 100,000 in 1976 (Paul 1984). India's malaria problem became aggravated when the number of reported cases increased from 278,000 in 1967 to 1,323,000 in 1971, and further to 5,082,000 cases in 1976 (Akhtar and Learmonth 1977). Thus, a resurgence of malaria occurred not only in Sri Lanka but also in India, Bangladesh, and other tropical nations. This

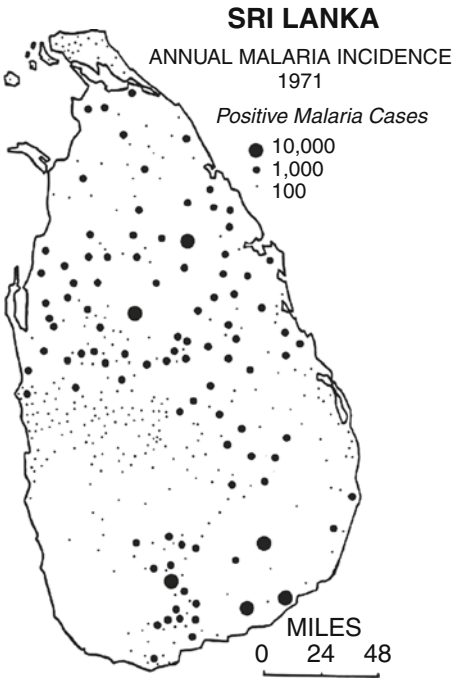


Fig. 2.2 Distribution of total positive malaria cases in Sri Lanka, 1971

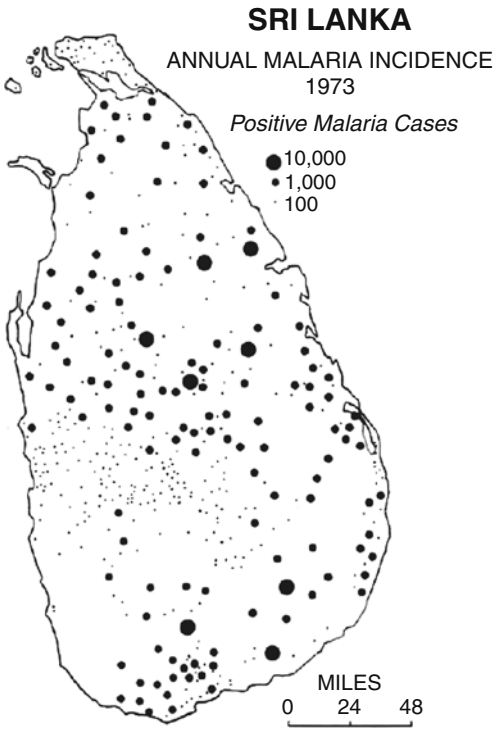


Fig. 2.3 Distribution of total positive malaria cases in Sri Lanka, 1973

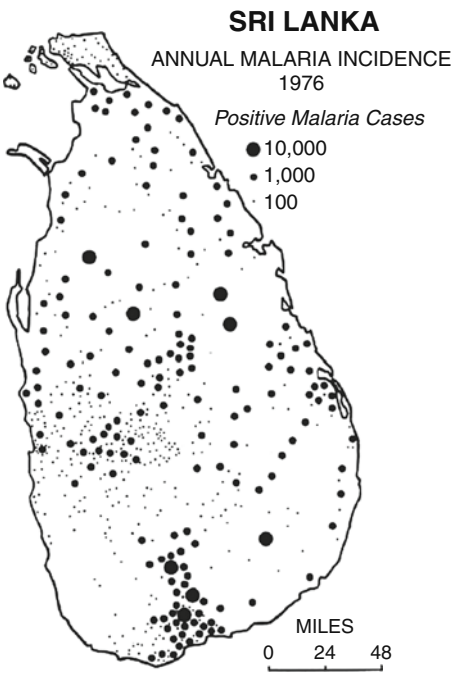


Fig. 2.4 Distribution of total positive malaria cases in Sri Lanka, 1976

situation prompted the WHO to abandon its hopes for the eradication of malaria and propose a "reoriented strategy" with goals of reducing malaria to negligible levels, alleviation of the effects of the disease on socio-economic development, and ultimate eradication of malaria "whenever feasible" (WHO 1979).

In Sri Lanka, resurgence in the dry zone reflected in the high rates of malaria incidence. Kahatagasdigiliya Health Subdivision in the Anuradhapura division lies in the heart of the dry zone. The highest rate of malaria incidence in the country was recorded here in 1971, with 213 cases per 1,000. In the following years the rate declined but still remained high, i.e., 89 cases per 1,000 in 1972, 184 in 1973, 99 in 1974, 168 in 1975, and 93 in 1976 (Table 2.1). In contrast, Colombo Municipal Corporation at the heart of the wet zone showed one of the lowest incidence rates in the country with less than 1 per 1,000 cases throughout the time span from 1971 to 1976. Table 2.1 and Figs. 2.5, 2.6, 2.7, 2.8, 2.9, and 2.10 indicate the number of positive malaria cases and rate per 1,000 for the country as a whole, and for selected health subdivisions of the country. The table reveals fluctuations in annual incidence in both zones and also shows that malarial occurrence was less significant in the wet zone.

The resurgence of malaria in Sri Lanka, along with that in other nations, was blamed on the complacency of malaria control officers and field workers, neglect of the mosquito breeding areas, vector resistance to DDT and other pesticides, *plasmodium* resistance to various drugs, lack of domestic and foreign government

Table 2.1 Positive malaria cases and rates in Sri Lanka, 1971–1976 (cases in thousand/rates per 1,000 people)

	1971		1972		1973	
	Cases	Rate	Cases	Rate	Cases	Rate
Sri Lanka	182.000	14	122.000	9	227.000	17
Dry zone Anuradhapura	9.300	61	3.600	16	9.400	58
Mannar (Jaffna)	1.500	21	0.600	8	2.400	32
Wet zone Baddegama (Galle)	0.027	*	0.048	*	0.057	*
Minuwangoda (Colombo North)	0.155	2	0.075	*	74.000	*
	1974		1975		1976	
	Cases	Rate	Cases	Rate	Cases	Rate
Sri Lanka	315.000	23	400.000	29	304.000	21
Dry zone Anuradhapura	16.000	97	25.700	122	13.000	59
Mannar (Jaffna)	3.400	45	4.200	49	4.800	54
Wet zone Baddegama (Galle)	0.148	*	0.230	*	0.123	*
Minuwangoda (Colombo North)	0.222	2	0.165	2	0.343	3

* Represents less than 1 per 1,000
Source: National Malaria Control Office (1972 to 1977).

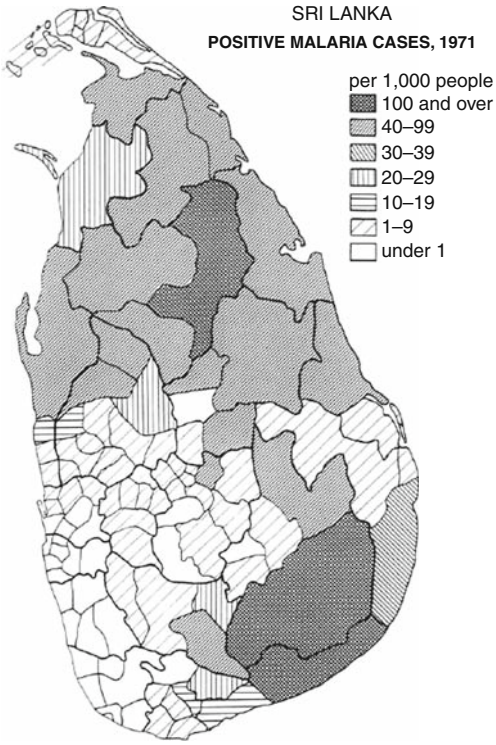


Fig. 2.5 Positive malaria cases per 1,000 persons in Sri Lanka, 1971

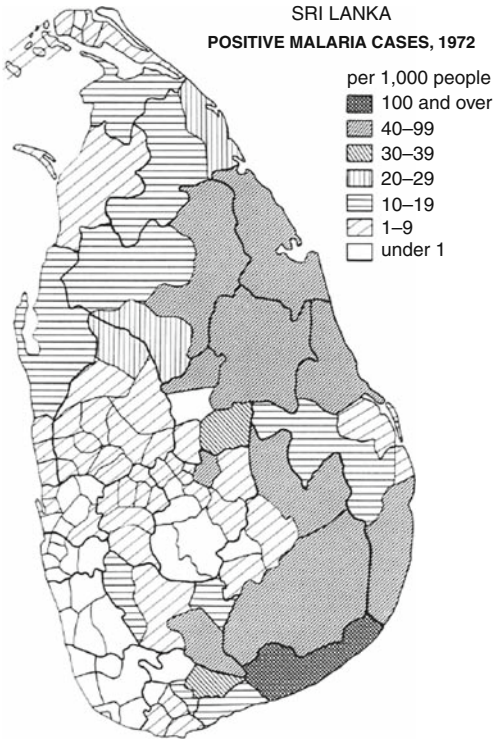


Fig. 2.6 Positive malaria cases per 1,000 persons in Sri Lanka, 1972

funds, and corruption in the malaria control agencies. However, one essential additional fact is also evident; a tropical nation with an underdeveloped economy, limited public health resources, an ecological environment favorable to mosquito breeding, and the ill-opportunity of constant population contact with the vector will face major challenges if attempting to totally eradicate the disease by spraying and administration of prophylactic medicines alone. With the active participation of the WHO, these were the only methods adopted by Sri Lanka and other tropical nations in the Post-World War II period.

During Sri Lanka's period of malaria resurgence in the 1970s, the disease established itself in the traditionally endemic dry zone. At its peak in 1975, malaria spread from two foci: one in north-central Sri Lanka and the other in the southeast. However, even during the period of resurgence, the malaria-free wet zone of the southwest remained relatively unaffected. No epidemics occurred even after the droughts, since malaria control authorities took immediate precautionary measures, i.e., spraying of streams. Presently, eradication of the disease by conventional medicines and pesticides alone does not appear feasible, though malaria mortality has been brought down to a negligible level.

A comparison of India, Bangladesh, and Sri Lanka reveals the disease's relationship with environmental factors and terrain. In the 1970s, malaria had not yet

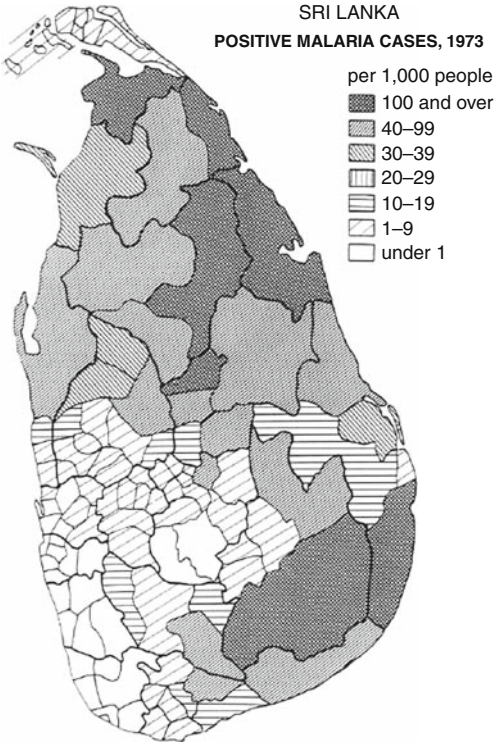


Fig. 2.7 Positive malaria cases per 1,000 persons in Sri Lanka, 1973

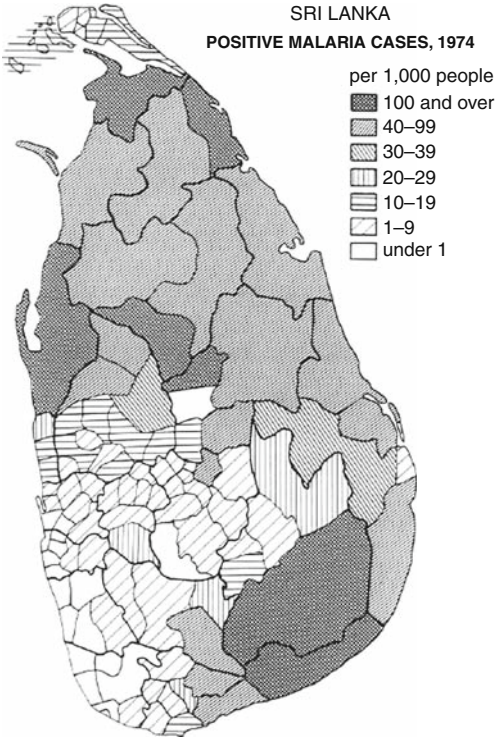


Fig. 2.8 Positive malaria cases per 1,000 persons in Sri Lanka, 1974

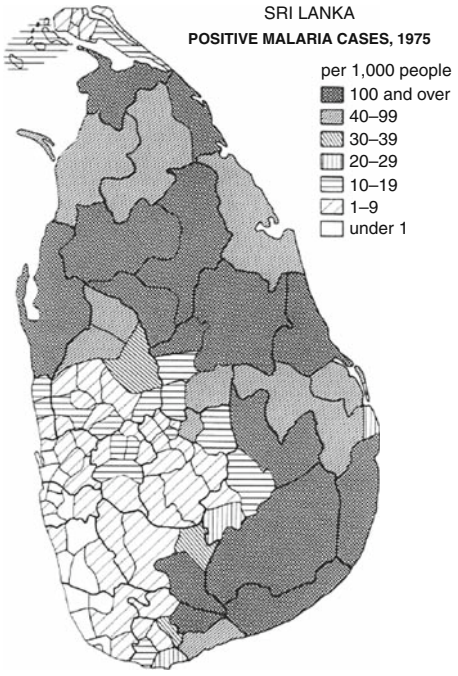


Fig. 2.9 Positive malaria cases per 1,000 persons in Sri Lanka, 1975

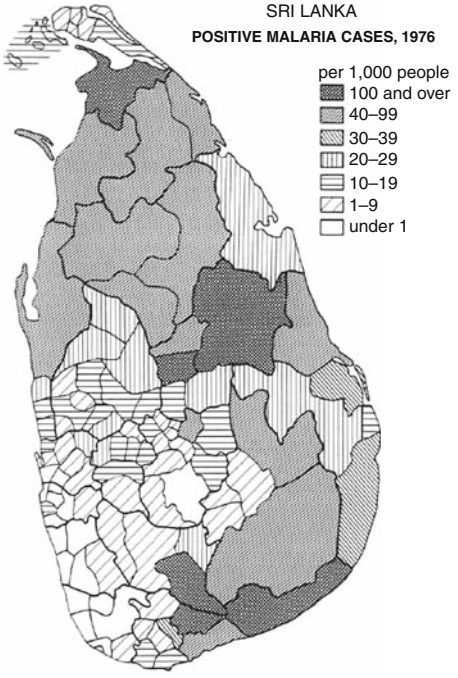


Fig. 2.10 Positive malaria cases per 1,000 persons in Sri Lanka, 1976

established a foothold in the traditionally endemic wet, populated plains of India and Bangladesh. However, the resurgence of the disease had already taken place in the dry endemic zone of Sri Lanka, some of which is characterized by hilly terrain and low population density. At the time, it was relatively easy to carry out anti-malaria campaigns in the plains because of better accessibility; this was true in both Bangladesh and India. In the relatively inaccessible hilly areas, malaria control was difficult, as was the case with Sri Lanka's dry zone. Moreover, it was more cost-effective and politically prudent to control the disease in the populated plain areas, rather than in the less populated hilly areas of the dry zone. Therefore, malaria resurgence was first evident in Sri Lanka's dry zone, where the physical environment was more conducive, and human intervention less feasible than in the wet zone.

Eradication: The Science Behind the Hunt for a Vaccine

During the resurgence of the disease, Sri Lanka's malaria incidence rate was much higher than that of India or Bangladesh, because unlike the situation in the latter countries, malaria was well established in the traditionally endemic areas of Sri Lanka. The resurgence of malaria and the intensity of its occurrence further indicated that with all else being equal, the disease is likely to persist in Sri Lanka, particularly in the dry zone. Vigilance and precautionary measures can negate the effects of occasional epidemics in the wet zone, therefore, the wet zone might retain its malaria-free condition. However, for complete eradication, discovery of an anti-malaria vaccine will go a long way in ridding the world's underdeveloped nations of malaria (Dutta et al. 1979).

In the summer of 1984, it was thought that genetic engineering had brought about a breakthrough in the development of an anti-malaria vaccine (Dame et al. 1984). It was predicted that by 1986, human trials could begin (Wallis 1984). Other follow-up articles revealed that researchers had used the powerful techniques of molecular biology, enabling them to clone genes of the malaria parasite. It was thought to be possible to unravel the complicated life cycle of malarial parasite and achieve "immunity to malaria. . .." (Kolata 1984). However, no effective vaccine has yet been discovered against a parasite disease, and the efficacy of such a vaccine for humans is not known. Moreover, some investigators feared that malaria parasites might become resistant to the vaccine as well (Kolata 1984).

Therefore, the discovery of an effective vaccine to combat malaria was not realized at that time. Vaccine development strategies for malaria depend on immunological responsiveness to candidate antigens like the zygote surface antigens and the circumsporozoite (CS) protein that coats the *sporozoite*. Scientists examined the response of humoral antibodies to the zygote surface antigens, and of T lymphocytes to the CS protein,[1] and found them to be very restricted or weak. Thus, this development did not hold much promise for a strong immune system response to the invading malarial infection, translating into a weak candidate for a vaccine (Marshall 1988).

Scientists have conducted human trials to prototype vaccines aimed at the mosquito-borne (or *sporozoite*) stage of the parasite. This is just one stage in the entire complex life cycle of the malaria parasite. After the mosquito injects *sporozoites* into the host body while drinking human blood, the *sporozoites* move rapidly through the blood to the host's liver. Inside the liver, they incubate for several days and then burst out in entirely new forms to infect red blood cells (RBCs). This blood stage exhibits an entirely different antigen *sporozoite*, and causes illness and death. The parasites undergo further developments in blood cells and are transferred back to mosquitoes when they bite again. The vaccine aimed at the *sporozoite* level cannot be 100% effective, because even if one parasite reaches the liver, it can create a full-blown infection. Therefore, scientists had to come up with a complex vaccine that could attack malaria at more than one stage and in several ways (see Chapters 1 and 10).

Teams funded by United States Agency for International Development (USAID) and the US Army tested two anti-*sporozoite* vaccines based on a protein taken from the malarial *Plasmodium falciparum* and found that they could induce immunity in very few volunteers, and that the duration of the immunity was very short. Therefore, in 1987–1988, the researchers were disappointed in their concerted efforts to unravel the fundamental mechanism of the immune system (Marshall 1988; Good et al. 1988).

Subsequent efforts at vaccine development have been discussed in the introductory and concluding chapters of this book. As of when this chapter was completed, no vaccine has been developed to confer full immunity against malaria, although there is always a possibility of developing one in the future. If and when this vaccine is applied in Sri Lanka and other malaria-prone areas, the disease will possibly be eradicated, as in the case of small pox. Once again, science might triumph over nature and environment, the effects of which will be modified or controlled to the advantage of humankind. Until then, malaria can only be prevented, controlled, and kept at bay.

Note

1. There are primarily two types of immune system response, humoral antibodies (found in body fluids) and cell-mediated responses (T cells or T lymphocytes are an example). While the function of both is to attack invading microbes, humoral antibodies act outside the cells by binding to and destroying the antigens, while cell-mediated responses destroy other [infected] cells.

References

Akhtar, R., and Learmonth, A.T.A. (1977). The resurgence of malaria in India 1965–1976, *GeoJournal*, 1(5): 69–80.

Dame, J.B., Williams, J.L., McCutchan, T.F., Weber, J.L., Wirtz, R.A., Hockmeyer, W.T., et al. (1984), "Structure of gene encoding the immunodominant surface antigen on the sporozoite of the human malaria parasite *Plasmodium falciparum"*, *Science*, 225(4662): 593–599.

Dutt, A.K., Akhtar, R., and Dutta, H.M. (1980), "Malaria in India with particular reference to two west central states", *Social Science and Medicine*, 14D: 317–330.

Dutt, A.K., and Dutta, H.M. (1985), "Disease dynamics in south and south-east Asia with special reference to India." In R. Akhtar, and A.T.A. Learmonth, *Geographical aspects of health and disease in India*. New Delhi: Concept Publishing Company, pp. 37–48.

Dutta, H.M., Dutt A.K., and Vishnukumari, G. (1979), "The resurgence of malaria in Tamilnadu," *Social Science and Medicine*, 13D: 191–194.

Farmer, B.H. (1967), "Ceylon." In O.H.K. Spate and A.T.A. Learmonth, *India and Pakistan: A general and regional geography*, 3rd edn. Bungay, Suffolk, GB: Methuen & Co. Ltd, pp. 786–824.

Good, M.G., Miller, L.H., Kumar, S., Quakyi, I.A., Keister, D., Adams, J.H., Moss, B. et al. (1988), "Limited immunological recognition of critical malaria vaccine candidate antigens," *Science*, 242(4878): 242–244.

Harrison, G. (1978), *Mosquitoes, malaria, and man: A history of the hostilities since 1880*. New York: E.P. Dutton.

Kolata, G. (1984), "The search for a malaria vaccine," *Science*, 226(November 9): 679–682.

Marshall, E. (1988), "Crisis in AID malaria network," *Science*, 241(July 29): 521–523.

May, J.M. (1961), *Studies in disease ecology*. New York: Hafner Co.

Miller, L.H. (1988), "Malaria effective vaccine for humans?" *Nature*, 332(March 10): 109–110.

National Malaria Control Office (1972 to 1977), *Administration report of the anti-malaria campaign for the years 1973–1976*. Colombo: Directorate of the Ministry of Health.

Paul, B.K. (1984), "Malaria in Bangladesh," *Geographical Review*, 74(1): 63–75.

Service, M.W. (1976), *Mosquito ecology: Field sampling methods*. New York: Halsted Press.

Spate, O.H.K. and Learmonth, A.T.A. (1967), *India and Pakistan: A general and regional geography*, 3rd ed. Bungay, Suffolk, GB: Methuen & Co. Ltd.

Wallis, C. (1984), "A major step is taken toward producing a malaria vaccine," *Time*, 13 August, pp. 70–73.

WHO (1978), *W.H.O. Chronicle*, vol. 32, no. 6, p. 226. Geneva: World Health Organization.

WHO (1979), *Seventeenth Report of the WHO Expert Committee on Malaria*, Technical Report Series No. 640. World Health Organization: Geneva.

Chapter 3
Malaria in Sri Lanka: A Geomedical Analysis[1]

Gisela Peters

Abstract This chapter investigates why and how malaria developed under the special environmental conditions in the South Asian tropical island of Sri Lanka in the 1970s. This decade is significant because the reemergence of the disease became an established reality by then, enough to trigger a serious investigation of it by the national government. The purpose of this ecological analysis is to help develop countermeasures and to support the drive to stamp out malaria.

Keywords Etiology · Epidemiology · *P. vivax* · *Anopheles culicifacies* · Malaria warning system

Etiology and Epidemiology

It is important to be familiar with the life cycle of the malaria originator (*Plasmodium*), the transmitter to humans (*Anopheles* mosquitoes), and the environmental conditions upon which they depend. In this respect, two characteristics are of special importance to the *plasmodia*, namely, their pronounced vector exclusivity (female *Anopheles* mosquitoes that feed on humans) and the influence of temperature on their rate of development (higher temperatures increase this rate) (Fig. 3.1).

The Malaria Originator

Of the three anthropophile *plasmodia* common in Sri Lanka, *Plasmodium vivax* develops the quickest. This applies to both its development period inside mosquitoes and inside humans. Under warm conditions in the tropics (temperatures equal to and above 25°C/77°F), a new generation is produced. It matures within 8 days and is transmitted from the variably warm body of the mosquito to the warm-blooded

G. Peters (✉)
Bad Homburg, Germany
e-mail: peters.gisela@t-online.de

R. Akhtar et al. (eds.), *Malaria in South Asia*, Advances in Asian Human-Environmental Research 1, DOI 10.1007/978-90-481-3358-1_3,

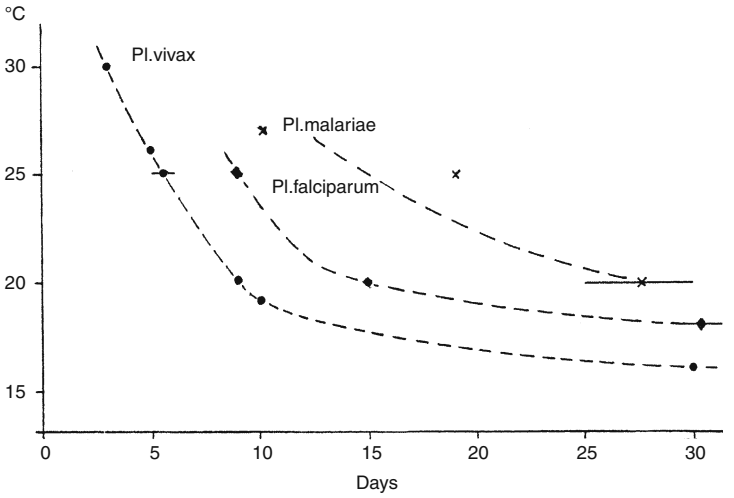


Fig. 3.1 Rate of development of various *plasmodia* (in days) in relation to temperature conditions (according to Nauck 1975; Weyer and Zumpt 1966)

human body, where its first anthropodial phase is completed within 2 days (WHO 1969).

P. vivax, P. falciparum, and *P. malariae* are permanent endoparasites that perish outside their host. They are, therefore, completely dependent on the biology of their host. Their rate of occurrence and reproduction, and their lifespan and development activities are governed by the fluctuations in the living conditions of the host. External geofactors that influence the presence of the human host with respect to distribution and density also influence the malaria pathogen. However, geographical–ecological factors have no direct influence on the *plasmodia* themselves. At no stage in their development are *plasmodia* as exposed to the workings of the biosphere as are their hosts (Nauck 1975; Weyer and Zumpt 1966).

The Transmitter to Humans

Of particular importance are the intermediate hosts, which enable the first phase of the *plasmodium*'s development. The malarial vectors of the *Anopheles culicifacies* species are particularly dependent on the environment; the larval and pupal phases are only realized in still, shallow, sunlight-penetrated, and oxygen-rich freshwater. It is also important that the young *Anopheles* respire oxygen from the air above the water surface since they cannot breathe anaerobically. Almost every large or small waterhole is a potential home to these mosquitoes: lakes, meanders, flooded pastures, puddles, and water-filled tree stumps are natural options. Artificial features such as reservoirs (storage tanks), irrigation trenches, wells, cisterns, coconut shell halves, and empty cans are also suitable. The mature female form of *A. culicifacies* is a compulsive bloodsucking flying parasite that bites humans and other

warm-blooded animals. All female *Anopheles* rely on mammals as a host and as a food source. They are ectoparasites living in the biosphere, which means that geofactors are decisive in the life of the *A. culicifacies* and influence it as extensively as the biological factor of food source (WHO 1972).

Typically, the mature female *Anophelene* has a lifespan of about 2–3 weeks in warm tropical climate. The *Anopheles* requires high relative humidity (80%); under dry conditions, she dies earlier. In its activities, the *Anopheles* shows a clear daily rhythm with peaks at dusk and dawn; she is active at night, usually resting during the day. For this rest period she seeks out dark, sheltered places away from direct sunlight, sometimes in human dwellings. The rate of metabolic exchange of the *A. culicifacies* is also closely related to the temperature level. In the lowlands of the tropics, a blood mealtime every 2–3 days may be necessary, resulting in a high level of biting activity (Service 1976, 204).

Environmental Factors: Human and Physical

Through their function as hosts, humans also influence the strengthening or weakening of the infection rate due to their varied population densities and migration patterns. They also have an effect on the reproduction area of the mosquitoes because they develop land for agricultural use, and in the process destroy natural environments for vector breeding while creating others.

In a 1957 model study, the World Health organization (WHO) evaluated how quickly malaria can spread from one single sufferer, under conditions favorable to pathogens and vectors in a nonimmunized population (WHO 1957). It was assumed for the study that malarial infection lasts 80 days after full incubation for the untreated malarial case, and that everyday a certain number of *Anopheles* are produced (in this example, ten) that feed themselves on the infected host. For an assumed *anophelene* death rate of 10% per day, 30% of the *Anopheles* survive 12 days and have a further life expectancy of 9 days. During this period, they will feed off four to five human hosts. Every initial sufferer can, therefore, further infect 540 other humans, causing the infection to snowball (WHO 1957). The "snowballing" effect is mainly dependent on the various *Anopheles*'s predilection for human blood. The principal course of the spread of the epidemic is always the same, with a hesitant starting phase that is sooner or later replaced by an explosive development.

Even if malaria in its most acute stages does not claim as many victims as other diseases such as cholera, it certainly affects the physical and mental development of the infected persons, and in the process weakens the economic power of a country. For example, the WHO estimated that in 1955, 130 million working days were lost to the Indian economy through malaria (WHO 1957). Every victim can be reckoned to have at least one relapse every year, each relapse lasting at least six working days. This despite the fact that this estimate does not take into consideration that every victim suffers lower productivity year round and is more susceptible to other illnesses, resulting in further loss of working days.

Given the shocking malaria situation in the first few decades of the twentieth century, the calls for a major campaign against this disease became more strident. The concerted campaign could only be started with the production of antimalaria sera such as Atebrin and Resochin, and the development of a simple and cheap insecticide (DDT), which happened between the First and Second World Wars. Although dichloro-diphenyl-trichloroethane (DDT) was discovered as early as 1874 in Strasbourg by German scientist Othmar Zeidler, the insect-killing properties of this chemical were first identified in 1939 by Paul Müller, Director of the Swiss company Geigy AG. As stated in Chapter 1, Müller received the Nobel Prize for Medicine in 1948 for this work.

The world then believed it had at its disposal the means to free humankind from malaria, and the WHO founded programs to eliminate it worldwide. The "Malaria Eradication Program" (MEP) was the name given to this effort, which, with correct implementation was to come to fruition within a matter of years. Malaria eradication implies the ending of malaria transmission, and the elimination of the reservoir of infective cases in a limited-time campaign carried out to such a degree of perfection that, when it comes to an end, there is no resumption of transmission (WHO 1957, S.4).

However, the malaria eradication campaign underestimated the power of the disease. A dramatic demonstration of this took place in Sri Lanka (then Ceylon), where malaria appeared to be eradicated by 1963, and all campaign measures were ceased. Later, an unpredicted malaria epidemic occurred with breathtaking speed. The vision of worldwide elimination of malaria appeared increasingly questionable as, in some places, the *Anopheles* and other insects demonstrated a resistance to the insecticides used against them. In Sri Lanka too, resistant strains were discovered, and soon after, the *Anopheles* developed a resistance to DDT.

Nevertheless, the initial successes in the control and elimination of malaria were impressive, giving grounds for hope that the aim of eradication could be achieved as in the case of smallpox. The rules and regulations governing malaria had hardly been researched then, and were not considered important because DDT was believed to be fully effective. It is true that the *Anopheles* vector remains the weakest link in the malaria chain as long as a malaria vaccine or longer-term medication is not available. The greatest promise of success appeared to be in attacking this link. However, the *Anopheleses*' ability to survive and adapt were underestimated, and by the later years of the twentieth century, it became clear that the time had come to investigate its living conditions, and to redefine and continue the malaria campaign from this point.

Therefore, understanding of malarial ecology has become an important factor in achieving the final goal of malaria eradication. The last half of the twentieth century had seen a number of such attempts to understand malarial ecology so as to formulate effective eradication strategy, either through prevention or through vaccine development (MacDonald 1957; Jusatz 1966; Weyer and Zumpt 1966; Domrös 1974; Learmonth 1979).

In the context of this chapter, it becomes pertinent to ask the question as to which tangible and relevant geographical consequences arise from the medical–biological

events described herein. In order to consider these events in an area at risk from or already infected by malaria, a clear ecological analysis comprising the individual components of the system must be made. These include

1. the full extent of the dependence of the malaria-originating *plasmodia* on their hosts;
2. the relationship between the malaria-transmitting *Anopheles* and their environment; and
3. the effects of human behavior on the promotion of malaria.

At this stage it is necessary to analyze the conditions that are specific to the spatial spread of malaria in Sri Lanka, taking into consideration the genesis and ecology of malaria in order to account for regional and temporal differences.

Documenting Malaria in Sri Lanka

Malaria was possibly widespread even in prehistoric times, undoubtedly aided by the intensive irrigation techniques with countless flat storage tanks and waterways, i.e., through the inadvertent provision of artificial surface water as a breeding ground for mosquitoes (Indrapala 1971). Malaria was also present on the island in colonial times (Carter 1927; Wigglesworth 1936; Gill 1936a; Ellison 1936). The main contribution of the 3-year investigation by Carter (1927) was the study of the regional distribution of enlarged spleens in 56,372 children; a simple but appreciably accurate method of assessing the extent of malaria through the body's reaction to the infection without recourse to laboratory diagnosis.

Compared to the normal distribution pattern of malaria in the 1920s, which highlights a clear-cut division between the areas with high and areas with low-to-negligible incidence of malaria, the extent of the spread of malaria infection in 1934–1935 is remarkable (Dickson 1935; James 1935; Briercliffe, Darlymple-Champneys and Wigglesworth 1936; Gill 1936b; Schilling 1936; Rodenwaldt 1937). During this abnormal epidemic, a total of 1.5 million people succumbed to malaria between mid-September 1934 and late March 1935—almost half the total population of 3.1 million—and the infection claimed 80,000 lives (Rodenwaldt 1937). The area of this epidemic extended from Chilaw and Dambulla in the North to Kalutara and Embilipitya in the South, encompassing the coastal range and hilly areas of the southwest sector to a height of up to 700–800 m (2,297–2,625 ft) above sea level. As a result, the inhabitants of these usually malaria-free zones where the population had virtually no immunity to malaria due to lack of previous infections (as reflected in the spleen index[2] of 1921–1923), were severely affected by the disease (Fig. 3.2).

The epidemic was almost exclusively transmitted by *A. culicifacies,* which would normally only account for 0.2% of the *Anopheles* larvae to be found in water collection points. During the epidemic they reproduced so rapidly that their

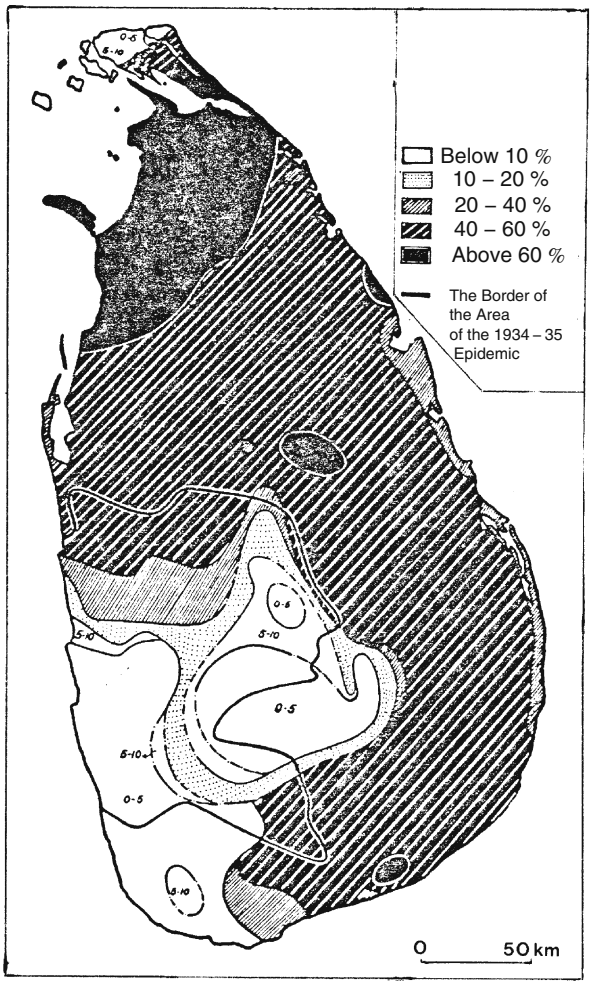


Fig. 3.2 Distribution of Spleen Index in Ceylon, 1921–1923, and the borders of the area of the 1934–1935 epidemic
Note: The Wet Zone coincides with "below 10% Spleen Index" area
Source: Briercliffe et al. 1936.

percentage increased to 29.5% (Schilling 1936). *A. culicifacies* represented 88.5% of the *Anopheles* species found in human dwellings in November 1934. Dissections performed on *culicifacies* females indicated that infection rate through them had reached 21% (Dickson 1935).

The cause of this epidemic can be attributed to a special atmospheric condition that seldom occurs in the Wet Zone. The Southwest monsoon season brought drought instead of the usual abundant precipitation. Only the area between Kalutara and Galle received sufficient rainfall, with the result that the characteristic freedom

from malaria could be preserved there. In the remaining Wet Zone, the rivers were reduced to stagnant water levels and could be used by the *Anopheles* as breeding grounds. This increase in the density of malaria vectors was in direct contrast to the number of persons lacking immunity, who could not overcome the development of the *plasmodia* in their blood. Their immune systems were weaker than usual since the failure of the rains had caused the rice harvest to perish, so the population was exposed to malnutrition and starvation (WHO 1965). This situation was further aggravated by the fact that the Wet Zone is densely populated, thereby exposing half the population of the nation to the infection.

After independence in 1948, campaign measures in the form of DDT spraying in the Dry Zone resulted in a successful reduction of the number of registered malaria cases from 2.8 million in 1946 to a mere 17 in 1963 (Weise 1974). This success led to an immediate ending of all DDT spraying programs. The fight against malaria appeared to have been won. The following years showed that this conclusion was premature; malaria had only been temporarily suppressed, not completely defeated. The campaign measures had been restricted to regular spraying of DDT. The complex malaria chain had been attacked at only one link without proper consideration of the external factors that: (a) influence the intensity and pattern of infection after a mosquito extermination program has been implemented, and (b) had only reached the female mosquitoes resting on house walls. This action had no effect on the true influences on mosquito density and level of infection such as the availability of breeding grounds in unstable malaria areas. The rapid recurrence of the infection in Sri Lanka (2.5 million cases in 1968) (Weise 1974) as well as in India (1.3 million in 1971) (Learmonth 1979) in the following years proved the ineffectiveness of this type of restricted spraying program.

A primarily state-financed investigation of malaria recurrence was undertaken during the period 1972–1979. At this time, phase two of the Anti-Malaria Campaign being conducted under the auspices of the WHO was also underway. The malaria campaign took place at three levels: (a) the spraying of insecticides, (b) epidemiological and entomological studies, and (c) treatment of victims. The single direct preventative measure in use was pesticide spraying. All houses, private and public buildings, walls, furniture, appliances, and any possible resting places for the blood-gorged *culicifacies* females were sprayed every 4 months.

DDT was thought to be an ideal solution for prevention activities because of its low cost and its high efficacy levels combined with low toxicity to mammals. However, DDT was eventually found by some studies to be toxic to the human nervous system (refer Chapter 1); it was used only until July 31, 1976 and was then replaced by Malathion, which is a contact insecticide. Malathion is absorbed into the insect body through its thin epidermis, beginning at the nerve endings in the feet and spreading through the entire nervous system. This initially leads to paralysis, and finally to the death of the insects (Weyer and Zumpt 1966). In Sri Lanka, 1% and sometimes 2% solutions were sprayed, because they remain chemically stable and biologically effective for several months. Other eradication techniques, such as the elimination of larvae in water by poisons or oil films, or the treatment with edible poisons of the plant food source of the male *culicifacies*, were not used in the

Anti-Malaria Campaign (Weyer and Zumpt 1966). Also not used were biological methods, such as the promotion of livestock farming as an alternative income source (other than agriculture that creates mosquito breeding conditions), or the breeding and release of natural predators such as larva-eating fish, viruses, and other micro-organisms which cause diseases in mosquitoes or their larvae. Genetic manipulation that would produce sterile males, or cause the atrophication of limbs or proboscis was also not carried out. (Gsell 1972).

DDT in conjunction with an antimalaria tablet-based therapy, at first the only weapon used against malaria, lost its effectiveness over the years, as confirmed by studies in various countries. Natural selection enabled surviving *culicifacies* to reproduce with high concentrations of the chemical in their tissues, or with a thickened cuticle which minimizes the absorption of this chemical or even detoxifies the substance by chemical treatment (Weyer and Zumpt 1966). These initially unusual characteristics were inherited by natural selection, so that in Sri Lanka the resistance of *A. culicifacies* to DDT became an increasingly widespread phenomenon and problem. Due to this reason, Malathion in 0.2% solution was used as a replacement spraying chemical. Malathion, an organic phosphoric acid ether that does not remain stable for as long as DDT, is more expensive and also represents an increased danger to humans (Weyer and Zumpt 1966). In addition, an even more rapid development of resistance to Malathion by mosquitoes had been observed in other countries. However, Malathion is one of the few substances that along with Diedrin and HCH (Lindan), both chlorinated hydrocarbons, Fenthion (an organic phosphorous compound), and Carbomaten (Propoxur), are suitable for major and widespread usage (Nauck 1958).

Study Data Set and Analysis

For the study period 1972–1979 discussed in this chapter, unpublished monthly statistics for subdivisions known as Health Areas were obtained from the Sri Lankan government and evaluated in addition to the material published from l971 to 1981 by Sri Lanka's Anti-Malaria Campaign (AMC), Directorate of the Ministry of Health (DMH). A Health Area is defined as an administrative area used by the National Health Service (NHS) for purposes of research, categorization, and action. Using data from 104 Health Areas, it was possible for the first time to differentiate between epidemic areas, malaria patterns, and time spans, and to recognize and establish their value for prognoses. This data facilitated the development of a malaria progression model for Sri Lanka.

Additionally, in order to estimate the nature and number of breeding places according to the manner in which they could arise, water sources that had measurable characteristics and thereby facilitated objective deductions were taken as representative of Sri Lanka's surface water. In the detailed investigation spanning 1972–1979, the water levels of 25 rivers were considered. An island-wide sample test was performed on the measured data of all rivers and storage tanks as collected by the Irrigation Department in Colombo (Fig. 3.3).

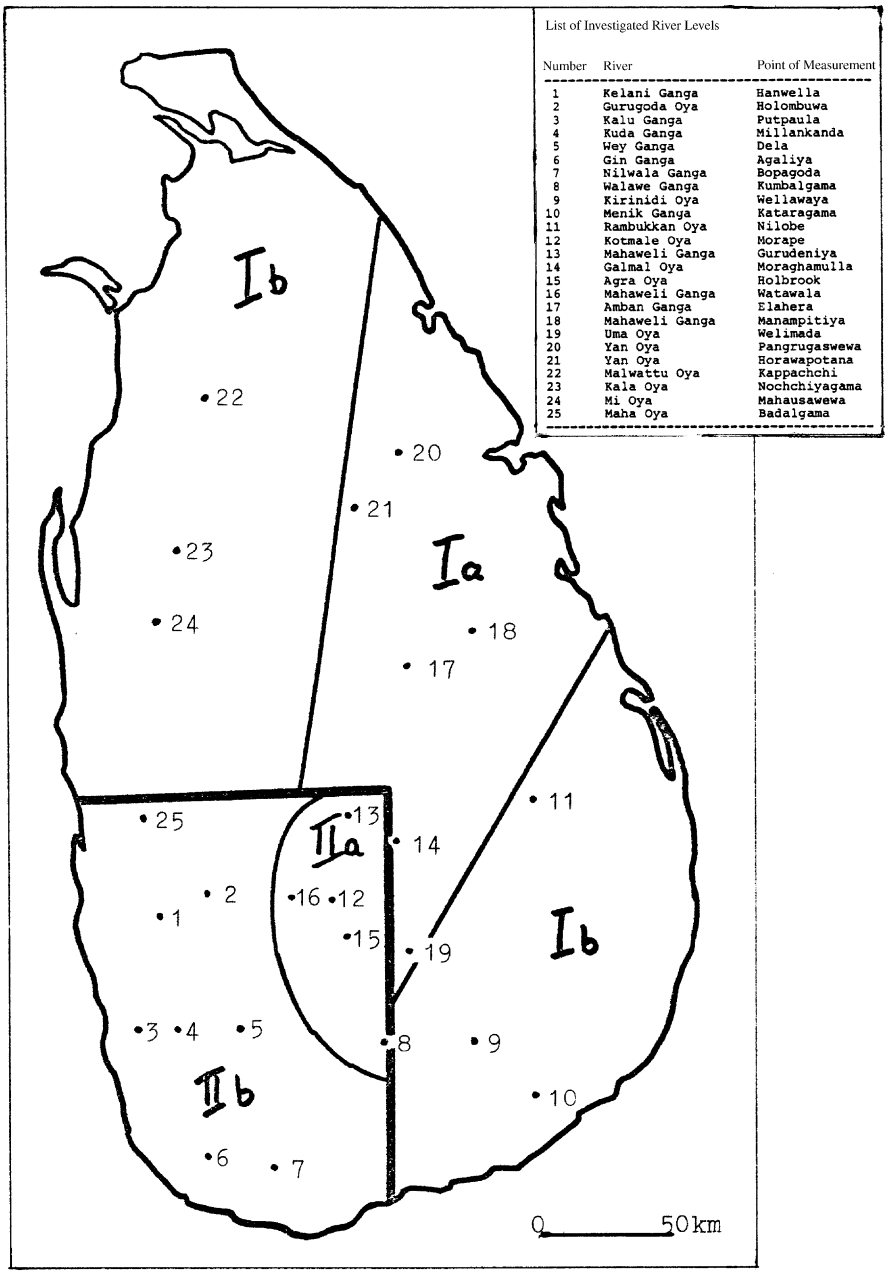


Fig. 3.3 Regionalization of the river levels investigated, with list of investigated river levels and points of measurement

The daily measured water level was taken as primary data for the analysis, enabling calculation of the high and low points for each month. This indicated the surface water available for use. The hydrological relationships were regionalized by cluster analysis based on monthly values. In this chapter, the model of malaria progression is presented first, followed by an analysis of the malaria situation based on the primary data set, an overview of geomorphological, cultural, and social determinants affecting malaria occurrence, and policy considerations regarding malaria control and possible elimination.

Phases of Malaria: A Model of Malaria Progression in Sri Lanka

The malaria documentation between 1972 and 1979 enabled the development of a model of how an epidemic might develop in Sri Lanka, contributing to an understanding of the causes and patterns of malaria transmission. The model showed that

1. there is a conspicuous distinction between the malaria-affected areas of the Dry Zone and the relatively unaffected areas of the Jaffna peninsula and the Wet Zone;
2. the Dry Zone clearly belongs to the category of endemic malaria areas;
3. superimposed on the above were seasonally changeable malaria epidemics;
4. malaria epidemics clearly spread through contact areas in accordance with a distinct pattern; they do not suddenly occur in distant and isolated areas.

Other observations led to the categorization of the process of malaria spread into the following six phases discussed below, which are apparent from Figs. 3.4, 3.5a and 3.5b.

Phase A: There are five centers of the epidemic, each being independent of the next:

1. Hambantota–Walasmulla–Atakampana–Moneragala in the south
2. Kilinochchi–Mullaitivu in the north
3. Dambulla–Naula–Rattota in the interior
4. Puttalam in the west
5. Valaichchenai in the east

Phase B: The above centers individually or collectively increase the danger of a malaria epidemic, increasing it to Alarm Level 1.

Phase C: Malaria does not spread out concentrically from these areas, but rather on defined paths or transmission routes, “corridors,” or “axes”, emanating

1. Northward to the Kahatagasdigiliya area
2. Westward to Anuradhapura and Kekirawa

3. Eastward to Hingurakgoda
4. Southward to Bibile

These corridors do not cease at their destinations; they also serve as transmission routes between the centers as well.

Phase D: At least two of the original malaria centers come into contact with each other by such a transmission route, and the danger of a malaria epidemic rises to Alarm Level 2.

Phase E: Once the above has taken place, the epidemic breaks out of these tightly sealed source areas into neighboring Contact Areas. Epidemics always meet in the

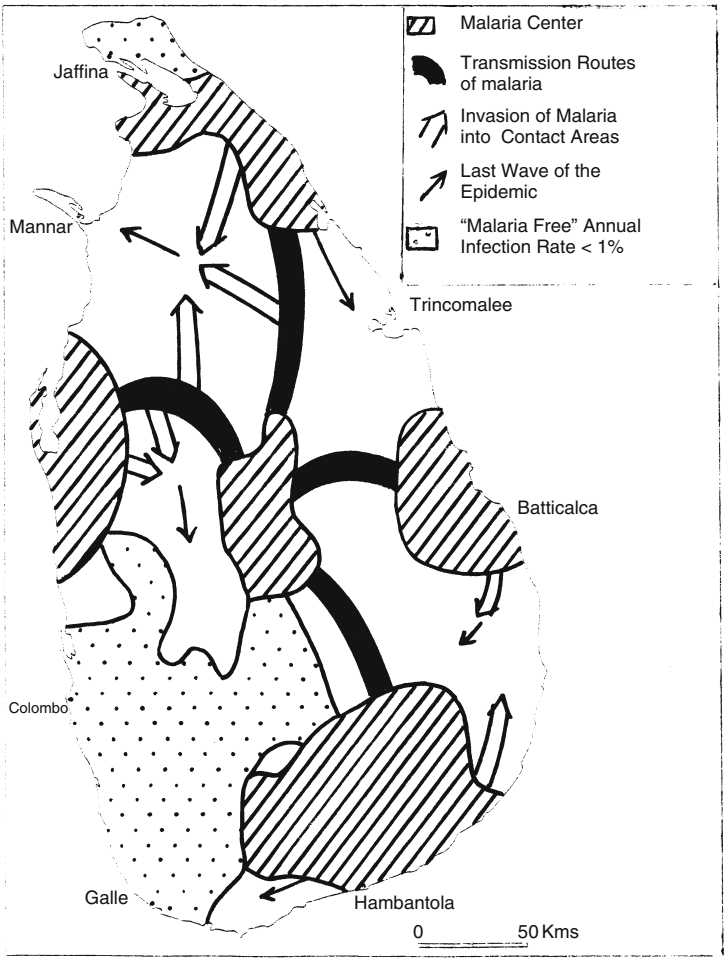


Fig. 3.4 Pattern of malaria incidence in Sri Lanka

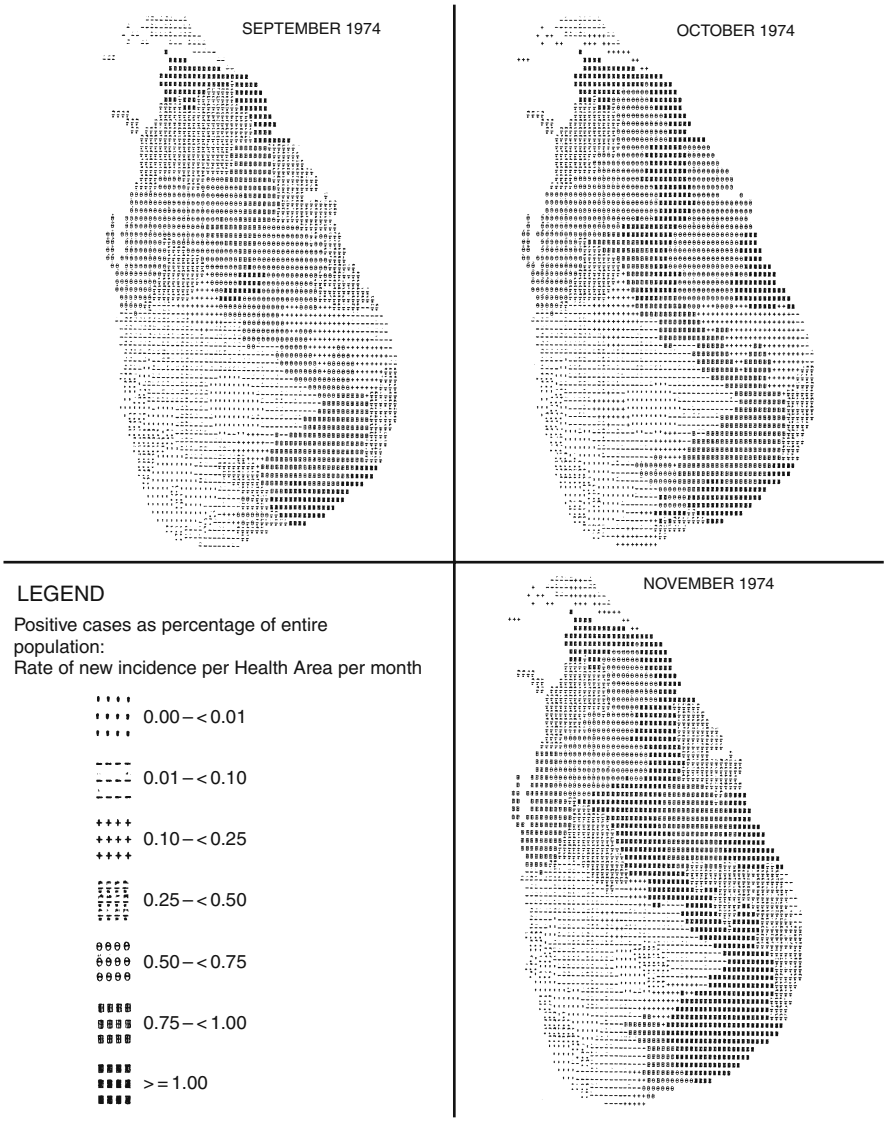


Fig. 3.5a The maximum progression of an epidemic during the observation period (December, 1974 to February, 1975)

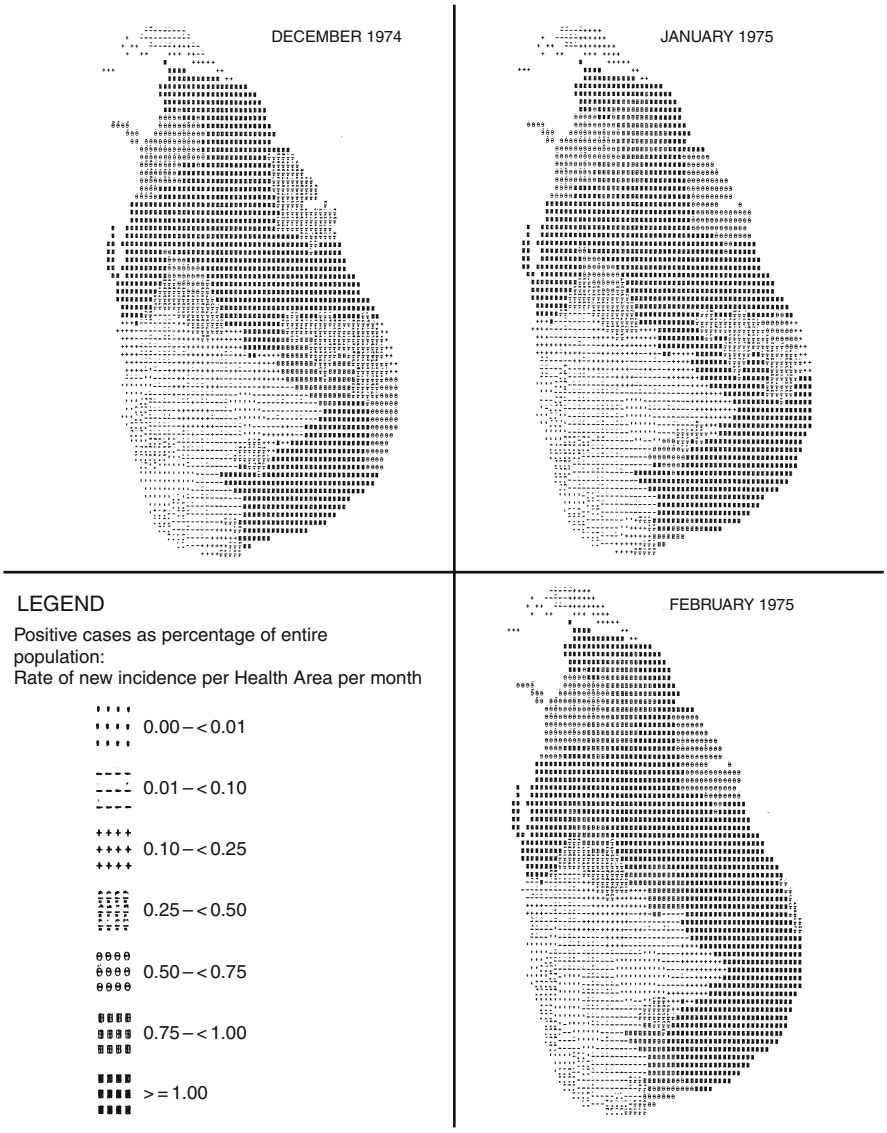


Fig. 3.5b The maximum progression of an epidemic during the observation period (September, 1974 to November, 1974)

same contact areas during their high points, and always in the same sequence. There are specific areas that reach Phase E more easily and earlier than others, namely

1. Vavuniya before Mannar and Trincomalee in the north
2. Galgamuwa before Maho in the south
3. Batticaloa before Amparai in the east
4. Tirukkovil before Tangalle in the west

The rule of thumb is that Phases B to E occur within 3 months, and explosive outbreaks cannot be excluded. It is also possible that only the first phase occurs before climax is reached and remission sets in. The peak itself can last several months.

Phase F: The remission occurs in reverse sequence to the advance, and can begin even before the advance of malaria reaches its final stage. It typically takes 1–3 months.

Seasonal and Spatial Variation of Malaria Occurrence

It may be concluded from the above model of malaria phases that (a) an epidemic always starts in the same areas; (b) control areas of Alarm Level 1 are the five malaria centers; and (c) control areas of Alarm Level 2 are the transmission routes.

Seasonal Occurrence

1. The five malaria centers are all of equal significance in terms of serving as an outbreak point, i.e., anyone can be the outbreak point of an epidemic. However, they are not equivalent, as they develop in different ways and spread to differing extents. The South Center is almost always at the top of the list, but has no significant encroachment area. It is followed by the North Center, which affects the Interior, Westerly, and Easterly areas.
2. Epidemics always occur at the same time of year: in April/May (*Yala* season), and in October/November *(Maha* Season). They are usually over by 6 months. The South Center is active during both the *Yala* Season (Southwest monsoon period), and the *Maha* Season (Northeast monsoon period). These two seasons often tend to merge, resulting in a perennial monsoon period. The North Center is mainly active during the *Maha* Season, but can stretch over into the new season at the year's end. The Interior Center is active during both epidemic periods, with short rest periods in between. The West Center is active during both peak periods, with pronounced intermediate minima. Malaria occurs in the East Center only during the *Maha* Season.
3. In combination with the Interior Center, the North Center is fundamentally the outbreak point for the *Maha* Season epidemics. It is neither a Control Center, nor a participating transmission center for the *Yala* Season epidemics. The West,

East, and South centers might also participate in the *Maha* epidemics; additionally, the West Center, which participates less frequently in the *Maha* epidemic, is also the outbreak point for the less significant *Yala* epidemic. The South Center, which participates less frequently in the *Maha* epidemic, is the main connection to the Interior Center during the *Yala* epidemic. The East Center functions only an outbreak point for the *Maha* epidemic.

4. The four transmission routes also develop in varied manners; the North Axis takes precedence over the West Axis, and the East and South Axes are also of less significance. The North Axis provides a transmission route during both seasons, and with short pauses can be maintained until the next peak period. The West Axis provides a transmission route during both seasons, but only briefly. The East Axis provides a transmission route only during the *Maha* Season. The South Axis provides a transmission route during both seasons, but for an extremely brief period of time.

The incidence of malaria between mid-September and the end of March between Chilaw–Dambulla and Kalutara–Embilipitiya, considered along with the epidemic from May to July 1976 suggests that possible epidemics within the Wet Zone start in the summer. They develop more quickly than those in the Dry Zone. The four regular malaria periods identified for the Dry Zone are: the two periods spanning November to December and January to March, during which the principal epidemic flares up or recedes, the period April through June that displays the first minimal state of the epidemic, and the period July through October that displays a light *Yala* epidemic followed by the annual low state of the epidemic.

In terms of seasonal patterns of malaria incidence, seven year-types were differentiated from one another: three regimes in the Wet Zone (peak in June, July, and August), and four regimes of the pronounced *Maha* Season epidemics in the Dry Zone, the Jaffna peninsula, the remaining northerly region of the island, and the east and south. The malarial seasons were deduced by means of computer calculations. Twelve distance groupings, with twelve variables (monthly values) from the data on 104 Health Areas were adopted for the purpose. The data were analyzed in four independent tests, with and without standardization, and with and without the proviso that only contiguous months may be combined. The results of every test indicated the same months falling into the four seasons—proof of their regular development. These seasonal variations in occurrence are reflected in Fig. 3.6a and b, where the former is essentially a regionalization of the 104 Health Areas based on period of new incidences of malaria as calculated above.

Regional Characteristics

The malaria periods generate the following characteristics and spatial patterns of the incidence:

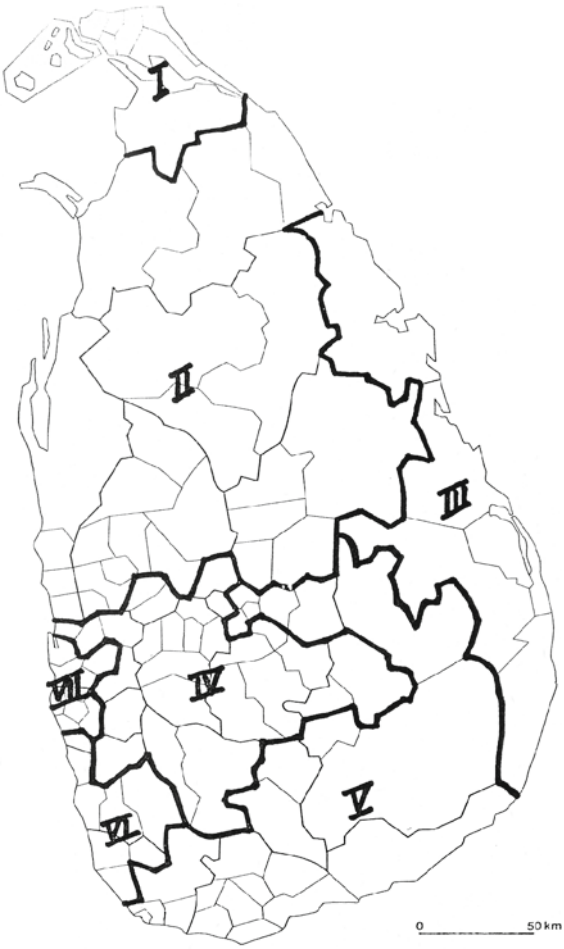


Fig. 3.6a Regionalization of health areas according to the periods of new incidences

Region	Name
I	Jaffna Peninsula
II	Northern Lowlands
III	East Coast
IV	Inner Wet Zone
V	Southern Lowlands
VI	Southwest Coast –South
VII	Southwest Coast –North

1. The malaria epidemics in the Dry Zone are transmitted from one of the five identified Centers to a neighboring area and do not break out willfully. The five malaria Centers are each independent of the next, from which the epidemics always take the same course through transfer areas or the identified malaria Axes that connect one center with another. Therefore, the course of the epidemic begins at Phase A, intensifies during Phase B in the five identified centers, progresses through the transmission routes during Phase C, connects the centers to

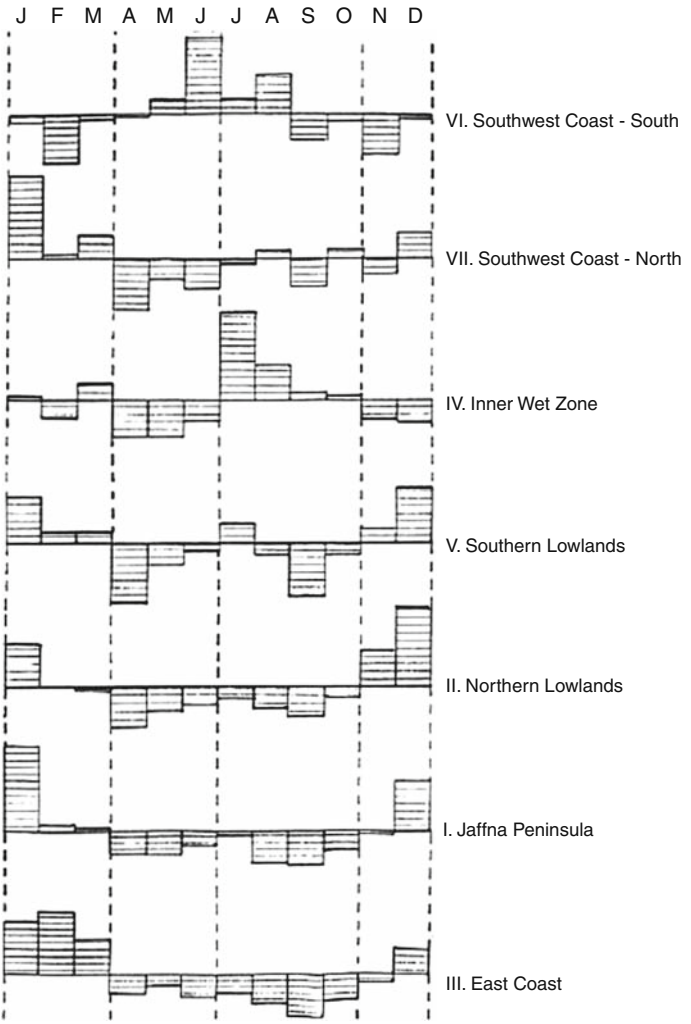


Fig. 3.6b Periods of incidences of malaria (standardized) in the various malaria regions

each other during Phase D, peaks in the contact areas during Phase E, and begins the remission process during Phase F. The South and North Centers of the Dry Zone are infected most frequently, while the most dramatically affected areas are the hills of the central mountain region, the entire Wet Zone, and the Jaffna peninsula.

2. However, the Wet Zone has a lower incidence rate but is "dramatically affected" since fluctuations within the year are greater than those in the Dry Zone, i.e., a spasmodic occurrence of malaria happens in the Wet Zone, wherein the rate of incidence can vary from greater than or less than the average rate within the

year. Increases and decreases can occur suddenly. In the Wet Zone the absolute maxima occur with a lower rate of infection, either during the seasons April to June (in the southern coastal section) or the season July to October (in the Wet Zone interior). These can develop into summer epidemics. An imported malaria peak can also occur during the season January to March.

3. Progression of malaria in the Dry Zone is sluggish. Its occurrence is mostly not unsuspected and it does not disappear without trace, but rather flares up and dwindles away. The larger peaks are heralded by a clear increase in the rate of incidence, and are followed by lesser peaks of incidence. In the course of the year, the peak of the malaria epidemic in the Dry Zone is reached first in the interior (northern and southern type), after which it spreads to the Jaffna peninsula and moves on to the east coast. The seasons in the Dry Zone can be summarized as below:

   (a) November to December—outbreak of the *Maha* epidemic.
   (b) January to March—peak of the *Maha* epidemic and the onset of remission.
   (c) April to June—low point (*nadir*).
   (d) July to October—summer *Yala* thrust with an ensuing annual low point.

4. The infection reaches its peak at the south coast first, and works its way inward such that the interior experiences its peak a month later.
5. Large swings such as accelerated thrusts, pauses, intensified remissions, and changes mainly take place at the ends of certain months, which indicate seasons in which the malaria situation remains relatively uniform (refer to dashed lines in Fig. 3.6b).

Analysis of the Malaria Situation

The primary data set indicating surface water availability at the regional level initially presented two contradicting principal flow regimes that coincided largely with the Wet and Dry Zones and paralleled each other in precipitation, reliability, and evaporation values. The classification of the rivers in the Wet Zone corresponded with the water catchment areas of the Southwest monsoon, and was analogous to the seasonal type of precipitation. It also matched the differentiation between underflow and over-flow areas. Such congruence was also apparent in the Dry Zone, where, with respect to the situation before the Northeast monsoon, the regime is divided into three subzones. One of these extends to the mountains, and the other two to the Northwest and Southeast, respectively.

In the Dry Zone, annual precipitation is low and extremely variable, evaporation is high, air is humid except during the Southwest monsoon period, and the water balance is seasonally negative. The water quantities here are not sufficient to flush out existing ponds. The precipitation creates a large quantity of surface water twice a year, i.e., in the second intermonsoon and the Northeast monsoon periods. It is only

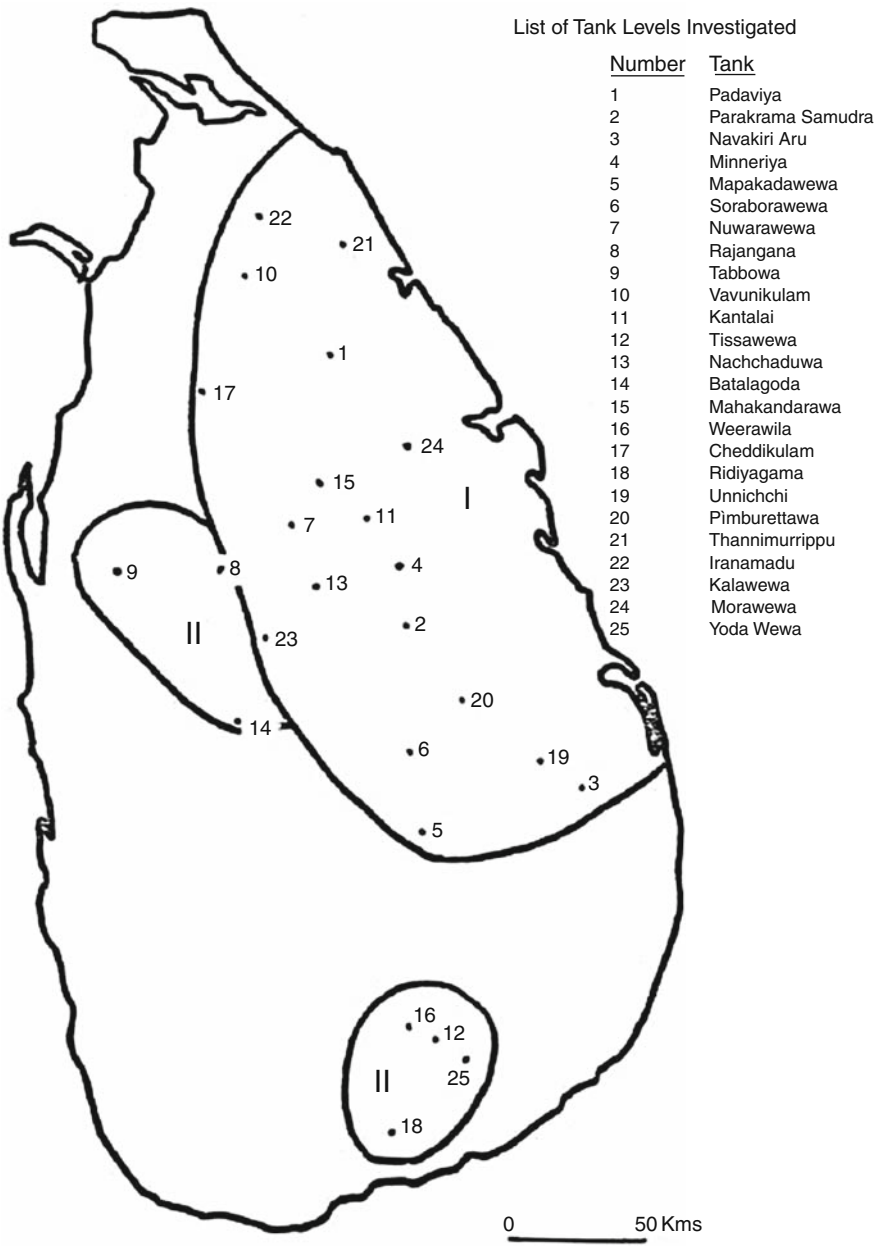


Fig. 3.7 Regionalization of the tank levels investigated, with list of tank levels investigated

enough to fill and flood the water sources. The precipitation is unable to flush out these sources, as precipitation only occurs over a short period, and between two dry periods. The available water in the Dry Zone fluctuates below the mean so that water evaporates continually, and isolated water sources are repeatedly formed, providing ideal breeding areas for malaria vectors.

The above classification of the flow regimes in the Dry Zone is supported by the distance grouping of the monthly maximal water levels in tanks (Fig. 3.7). This grouping distinguishes between the water catchment zones I and II. These stagnant water sources must be viewed from the ecological standpoint as potent development areas for the larvae, even if the water depth is decisive as to their quality. Quantitative examination makes it clear that the northern and eastern parts of the island have significantly more breeding places than the west, where no tanks are to be found.

The extreme northwest must be excluded from the above-described lowlands as it has a very chalky soil composed of miocene chalk.[3] Surface water drains into it, leading to a rise in the groundwater level, almost to the surface. The water tanks in this area are almost exclusively groundwater supplied, and typically lack above-ground drains. In addition, groundwater marshes, water holes, numerous artificial springs, and irrigation channels represent a high potential for mosquito breeding.

The surface water availability analysis brings up a number of considerations regarding conducive breeding surfaces for the *Anopheles,* due to accompanying factors that might hinder or encourage malaria occurrence, as discussed below.

Promotive and Inhibitive Factors for Malaria Occurrence

The spatial and temporal dimensions of malaria depend on intra- and extra-corporeal factors. Intra-corporeal factors refer to the *plasmodia*'s or vector's dependence on the host's body, while extra-corporeal factors include external aspects such as climate or geomorphology.

Intra-corporeal Factors

When the ecological climate in different parts of the country develops in the same manner at the same time, it does not imply that the same level of infection will be reached everywhere simultaneously. This is because according to intra-corporeal rules, the *plasmodia* must first be transmitted through people and *Anopheles* in order to spread over the country. This is one reason why malaria occurs even in areas with highly unfavorable conditions for mosquitoes. People coming from infected parts of the country are able to pass on the infection to the relatively few mosquitoes. For this reason an epidemic does not flare up in the same manner in all parts of the Dry Zone, but rather works itself slowly forward, whereby an increasing number of mosquitoes and people are affected.

Another internal corporeal factor is the immunity level of the native population; in areas that are repeatedly afflicted, population immunity is high. This has a braking effect on the speed of progression of the epidemic, whereas epidemics occurring in immunity-free or low immunity zones develop quickly and unhindered.

Extra-corporeal Factors: The Critical Role of Precipitation

As the documentation of the situation from 1972 to 1979 indicates, the high point of the epidemic does not occur simultaneously with extra-corporeal factors, but rather according to its own rules. This documentation also clearly identifies the peaks in the seasons. The external conditions for the possible development of malaria must occur first, then take root if contact to a core area is present. This is why the greatest incidence of the disease first appears only in January in the Jaffna area.

The malaria situation in Sri Lanka as described in this work has been analyzed for regional and temporal variations of its occurrence. The basic distribution of precipitation is the first critical factor affecting these variations, since the extent of breeding possibilities for the *Anopheles* larvae increases and decreases with precipitation. The greater the number of water sources, the greater the number of larvae which can develop into adults, and thus, greater the number of mosquitoes which are available as vectors of the *plasmodia* to continue to infect one victim after another. It is incorrect to make the generalization that seasons with high precipitation are always malaria-free and that seasons with low precipitation always result in an epidemic. An irregular pattern of precipitation also triggers malaria incidence and epidemics.

Expressed in another manner, it is the magnitude of deviations from the mean that determines whether or not an epidemic occurs. If the mean is high, as in the Wet Zone, then only significant deviations below the mean can lead to epidemics. Slight increases lead to a higher rate of malaria incidence, just as slight decreases in precipitation reduce the number of breeding places. An epidemic does not occur in the latter instance since the surface features are still continually filled and flushed with water to almost the same levels. Therefore, there is no trigger effect for an epidemic. However, a precipitation rate which is considerably below the average, which is atypical for the Wet Zone, sharply increases the availability of breeding places because of drying out of flowing water, with the result that an epidemic can easily break out here.

Should the mean rate of precipitation be low, and the pattern of precipitation throughout the year irregular with sharp deviations as is typical for the Dry Zone, then the water regime is always the same for both an above average water volume and a drought. Also, from time to time the overflowing water fills surface features that are not connected to the waterflow system. This still water becomes a breeding place as quickly as those isolated water points that are created when water dries up during a dry period. Continuously decreasing precipitation diminishes the evaporation of the surface water and the epidemic slowly subsides, with the rate of incidence

dropping to a pre-epidemic level. However, even the decreased level of precipitation remains sufficiently high for breeding places to form and cause a new epidemic to occur, leading to a rate of malaria incidence that is always higher as compared to the Wet Zone that has a regular pattern of precipitation.

Should a period of continuing aridity occur, lack of flowing water becomes the norm almost everywhere, as in the extraordinary year of 1975. The water channels broke up into isolated puddles and even the intact water sources of every type and size presented ideal breeding surfaces. This in turn became a catalyst for a new epidemic. However, an extended period of aridity, which was not registered during the observation period, would presumably bring the epidemic to an end, since the disappearance of surface water would result in a lack of insects. It can therefore be concluded that in order for *A. culicifacies* to breed successfully, still and shallow water must be available, and large water surfaces are just as suitable as small puddles.

Other Human Factors Influencing Malaria Occurrence

Humans merit special observation as a natural factor in the development of malaria, since they play host to the *plasmodia* as well as the *Anopheles*. An increased or reduced rate of malaria incidence is thus related to the density of the human population in the area.

Cultural Factors

Ethnicity is also a significant factor due to its ties with cultural practices. The west and south coasts were principally inhabited by lowland Singhalese (over 75% of the population), the interior by Kandy Singhalese (50–75%). The north, and to a lesser extent the east coasts, are inhabited by Sri Lankan Tamil Hindus. Over 50% of the population of the Nuwara Eliya district in the central highlands comprises Indian Tamils, and more than 45% of the Amparai district is inhabited by Ceylon Moors (Muslims).

The significance of cultural geographical factors on the development of malaria is that central to the aspect of ethnicity are the social conventions and traditions, and how they affect the level of malaria infestation. The type of tillage and husbandry, migration patterns, process of raw material extraction as determined by religious practices are important. This is because *A. culicifacies* is not entirely dependent on one host but seeks out all warm-blooded animals. However, *P. vivax*, *P. falciparum*, and *P. malariae* can only develop further in humans. A study carried out by the Anti-Malaria Campaign in Sri Lanka revealed that from the 836 captured *A. culicifacies*, only 16% were nourished by human blood; the remainder had fed on cattle, dogs, goats, and other mammals (National Malaria Control Office [NMCO] 1973). As a consequence, the greater the numbers of animals present in an area as an alternative blood source, the lower the incidence of malaria in humans.

Tamil Hindus consider the cow to be holy. Therefore, wherever this ethnic group is in a majority, a large number of cows are also found, which provide an alternative blood source. The centers of Tamil inhabitation are found on the Jaffna peninsula, which is almost malaria-free, and in the populated districts of Mannar and Vavuniya. In the Health Areas of Mannar and Vavuniya, fewer cases of malaria were registered than for the lowland and Kandy Singhalese areas, which are the remainder of the north-type malaria season in the Dry Zone. This decrease in incidence can be largely attributed to the high number of beef cattle found in the area, especially given that the physical/geographical factors present would lead one to expect a gradual increase in the intensity level of malaria[4] compared to that found in Kilinochchi and Mullaitivu. In these two areas, a high variability of the precipitation provides for a seasonally high availability of breeding places for *Anopheles* and thus would suggest a high malaria incidence.

The population in the Health Areas mainly inhabited by the Muslim Moors (i.e., along the east coast) is also comparably less infected. The Moors keep goats on which the *A. culicifacies* also feed. Galle has the absolute minimum of malaria incidence because it has a high proportion of Muslim inhabitants where goats are raised in large numbers. The availability of animal hosts for the blood sucking malaria mosquitoes is crucial in order to reduce or eliminate the risk of malaria in humans. Additionally, the proportion of Tamils is greater here than that of the Singhalese.

Town Infrastructure Deterioration

When malaria intensity in densely populated Health Areas with higher rates of population expansion, namely Dehiwela and Kandy, followed by Jaffna, Negombo, and Matara, is compared to the malaria intensity in their respective less-populated hinterlands, it becomes apparent that the above five areas have one important common factor; they all have higher infection rates than their hinterlands, even though they each lie in completely different malarial environments. These five areas are representative and typical of all Sri Lankan towns in that they are more severely infected than the rural districts. Town infrastructure is characterized by slum and shanty buildings, inadequate water supply, poor hygiene, and general negligence, so that in every urban area, more manmade breeding places exist (tree stumps, empty tin cans, overgrown building sites, trenches, and refuse heaps) as compared to the rural hinterlands, even though the rural areas also have many areas suitable to vector breeding.

Cultivation and Irrigation Practices

On the basis of physical/geographical conditions and different ethnicities, a number of socioeconomic areas can be delineated. The wet southwest economic area, especially the warm tropical lowland, allows the inhabitants to farm easily and intensively, and to live in close proximity to each other and their farms. Here, small

holdings rub shoulders with large estates. The entire land surface is cultivated intensively, which requires careful drainage and a drastic reduction of the natural water source. In contrast, the land use in the Dry Zone economic area is not intensive. Here, storage tank irrigation is necessary to compensate for irregular precipitation and to prolong the effect of the rainfall. In the interior, the Singhalese cultivate their rice using seasonal, storage-tank irrigation. The land there seems littered with flat, stagnant village tanks, which are exposed to sun and evaporation. Water is collected and stored during the Northeast monsoon period, with the result that this type of cultivation offers favorable surface water conditions for the *Anopheles* to significantly increase their populations.

The area consisting of the land outside the irrigated areas can only be extensively farmed aided by the Northeast monsoon precipitation. For this, the Singhalese have developed the *Chena* cultivation system, in which they continually burn new parts of the monsoon forest and bring it under cultivation for a short time. Comparisons of malaria intensity rates show that the burnt areas predominantly correspond to the areas worst afflicted by malaria. Puttalam, Anuradhapura, Kahatagasdigiliya, Kekirawa, Dambulla, and Naula in the interior are as malarial as the *Chena* agriculture centers. In between the burnt areas of *Chena* centers lie Gokarella, Kurunegala, and Matale that are noted for their low rates of malaria incidence.

The rate of incidence is also lower in the northerly districts of Mannar and Vavuniya, where the resident Tamil populace does not practice *Chena* farming. This is also the case for the east coast districts of Trincomalee and Tirukkovil, where the local Moor farmers too do not practice *Chena*. In between, around the hills, lies a belt consisting of the districts Rattota, Bibile, Moneragala, Atakalampanna, Walasmulla, and Hambantota, which are severely infected. They are farmed by the *Chena* system. This thickly populated belt, which uses the Singhalese farming technique, is noted for its high malaria incidence. This can be attributed to the fact that the long fallow periods in the rice cultivation lead to decaying rice terraces, earth banks, and water channels, the abandoning of the infertile *Chena* areas, and the collapsing of the temporary *Chena* huts. All contribute to an increase in the number of favorable water sources for the *Anopheles*.

In the Dry Zone, the low malaria incidence in the Jaffna peninsula is noteworthy. Precipitation is particularly unreliable around Dambulla, the Hambantota region in the center of the island, the west coast between Puttalam and Mannar, and the northern edge of the mainland. The corresponding Health Areas of Hambantota, Kilinochchi, and Mullaitivu indicate the severest malaria incidence in Sri Lanka. However, the Jaffna peninsula district is inhabited by Sri Lankan Tamils who practice surface intensive horticulture, and the carefully farmed, intensively tended fields lead to a drastic reduction in stagnant water.

Generally, land cultivation with a regulated irrigation system is one of the most influential malaria-hindering factors. In contrast to the precipitation and temperature relationship, this is an instrument that can be used and mastered by humans. As demonstrated by the efforts in Jaffna, it also offers a long-term solution as compared to spraying actions. Some of the ways in which various irrigation methods impact malaria occurrence are discussed below.

Tanks: There are two conflicting impressions of the malaria threat. One, the development of land in the Dry Zone through both modern and restored tanks can increase *Anopheles* breeding surfaces. Contrastingly, the intensive inhabitation and farming of the Jaffna peninsula has resulted in the disturbance of the natural living conditions of the *Anopheles*, thus reducing the incidence of malaria. Development projects that intensify farming in the Dry Zone in a planned manner can also improve the situation by regulating agricultural methods. However, these projects also rely on attracting inhabitants from the population centers on the west coast, whereby a population with no malaria immunity is moved to a malaria prone area. These projects could thus result in a higher malaria incidence than was prevalent at the time when the project was initiated.

Development Projects: The first project initiated after Sri Lanka's independence in 1948 was the Gal Oya Development Project. At the time this study was undertaken, it was yet not apparent whether the project would contribute toward the reduction of malaria incidence, although promising malaria trends in that direction were observable in Amparai, which, together with Bibile, comprises the land bordering on the Senanayake Samudra tank that was part of the project. The Gal Oya project was eventually judged an economic and financial failure (Domroes 1976), but it had made possible the control and restriction of the previously unpredictable flooding of the Gal Oya River by means of 14 interconnected regulating tanks. As a result, almost half of the newly laid out rice paddy farms were guaranteed two harvests a year, which in effect lead to careful and intensive agricultural techniques, implying lower malaria incidence.

The Uda Walawe Reservoir lies on the border between Atakalampanna and Moneragala districts. Although the land was settled only between 1968 and 1970, malaria intensity trends from 1972 to 1979 gave little cause for hope of improvement in the malaria situation. This can be attributed to the drawing of Health Area borders through the middle of the lake, and to the extensiveness of the Health Areas themselves. The author's visits to Sri Lanka (and particularly to the River Valley Development Board) for research and data collection in March 1974 and September 1977 showed a marked increase in the neglect of the land over this time span. Therefore, no improvement of the land was expected at the time, and the districts of Atakalampanna and Moneragala remained among the most infected on the entire island.

As a last example, the effects of the Mahaweli Development Project on the course of the malaria infection should be considered. Its commencement in 1970 with the construction of the Polgolla Dam near Kandy took place just early enough to allow the first results to be evaluated for this study. However, after the water level increased, an epidemic broke out in 1976 to the west of Kandy.

Although this area previously had a low malaria incidence like the other areas in the Wet Zone, the change in the water situations provided the requisite conditions for an epidemic. As the Anti-Malaria Campaign became aware of this, the project leaders were contacted. It was decided that the sluice gates should be opened every Sunday morning from 3:00 a.m. to 6:00 a.m. in order to flood the ponds of the Mahaweli and thus flush out the *Anopheles* larvae (NMCO 1976). This proved

sufficient to improve the epidemic situation to such an extent that since January 1978, this area returned to its usual low rate of malaria.

The unfortunate beginning of the Mahaweli project should not lead to an adverse assessment of the undertaking, which planned to make the majority of the Dry Zone arable. However, it is a warning that should not be ignored under any circumstances. The planning phase of such farming development projects must consider the possibility of similar adverse effects when ecological conditions are changed. In general, the chosen path of agricultural intensification must be approved in conjunction with malaria eradication measures, since land clearing seems to be the only real solution to the malaria problem under these specific circumstances. Not only does land clearing present no threat to long-term human health, it is also more effective than the use of chemical and medical treatments, which result in resistance phenomena. Additionally, it secures a food supply for the population via development-project sponsored farming, raises overall nutritional levels, and secondarily raises population immunity to diseases such as malaria.

Policy Considerations Arising from the Study

Rivers and Tanks as Indicators of a Malaria Epidemic

The Puttalam and Hambantota districts are considered typical examples of malaria-affected areas in the Dry Zone. Significant positive correlations between new cases of malaria and water levels monitored in rivers and tanks suggest that both Health Areas can serve as alarm districts for the malaria campaign because these are the two Malaria Centers in the west and south, respectively, that serve as outbreak points for epidemics. They contrast strongly in their year-round status, in their affiliation to already active epidemics, and in their degree of affliction by the epidemic. In addition, they are starting points of malaria transmission routes north toward Kahatagasdigiliya.

There are 12 river level monitoring stations in the Dry Zone, which when combined with the 61 Health Areas of the Dry Zone malaria types, yield 732 correlation coefficients. The additional 25 tanks in the 61 Health Areas produce a possible 1,525 combinations.

Unlike rivers, storage tanks are not only representative of the precipitation-determined fluctuations in the malaria season, they are also subject to human influence in terms of the extent of the storage and irrigation practiced. These aspects in turn affect the amount of surface water available to the *Anopheles* for breeding. In the Malaria Centers, it has been observed that malaria favorable conditions multiply as human influence (tank filling) coincides with natural influence (river water levels), and contribute considerably to the occurrence of epidemics.

The collection of hydrological measurement data is helpful in effectively combating malaria. Water levels in selected rivers and tanks are useful indicators of

the danger of an epidemic; they permit effective malaria prognoses and can be the starting points of malaria combating measures that may enable avoidance of the infection.

The Districts of Sri Lanka as Malaria Clearing Areas

Once the causal structure of malaria epidemics is recognized through the analysis of average and actual courses of malaria in its normal and abnormal characteristics, a new synopsis consisting of malaria areas of varying quality and potential can follow. A new "ecological" malaria campaign can be developed from this. Figure 3.8 displays the ecological topography of malaria in Sri Lanka.

Natural factors that determine the topographical suitability for the development of malaria infection are extracted based on regionally classified temperature patterns, which influence spore production of the *plasmodia* and the propagation and speed of development of the *Anopheles*. Equally important is the geomorphology of the area, which determines the quantity and quality of the *Anopheles*' breeding places. With the exception of the hill country, which can be ruled out as a potential malaria district on the basis of its temperature and precipitation characteristics, the entire area of Sri Lanka is threatened by malaria, albeit to different levels of intensity based upon the natural regional and seasonal infectious tendencies.

The majority of physio-geographical viewpoints differentiate between two contrasting malaria propagation areas, the Wet and Dry Zones. The Wet Zone is also differentiated by its high population densities and intensive land use. As compared to the Dry Zone, the ecological structure in the Wet Zone offers fewer conditions favorable to the spread of malaria. From the High Plains, the Uva Basin and the Hatton Plateau (Area I) the risk of malaria increases in direct proportion to the decrease in height above sea level. As the water-retaining red loam clay begins to appear, the precipitation level and resulting flooding decrease. The result is a natural tendency toward malaria infection in the southwest part of the lowlands (Area II). The farming techniques practiced in the Wet Zone have an inhibiting effect on the risk of malaria. However, the high population density increases the risk factor. Abandoned quarries and gem pits also present an increased potential of danger, the latter found particularly in the Ratnapura rift between Eheliyagoda and Pelmadulla. These are as just as likely to be the source of a prolific mosquito population as the humanmade water holes in the urban areas.

A major malaria campaign is unnecessary in the Wet Zone. It is sufficient to draw attention to the need for cleanliness in the towns, particularly during the peak rainy period of the Southwest monsoon, and for covering and filling up of pits. In addition, if all malaria cases were isolated at least overnight, i.e., during the period of greatest mosquito activity, then the Wet Zone could be kept malaria free. This could be done in hospitals, dispensaries, and other mosquito-free buildings, using mosquito nets, fans, and spraying and spreading of mosquito repellents. Given the low malaria risk in the Wet Zone, the concentration of malaria campaigns is recommended in the Dry

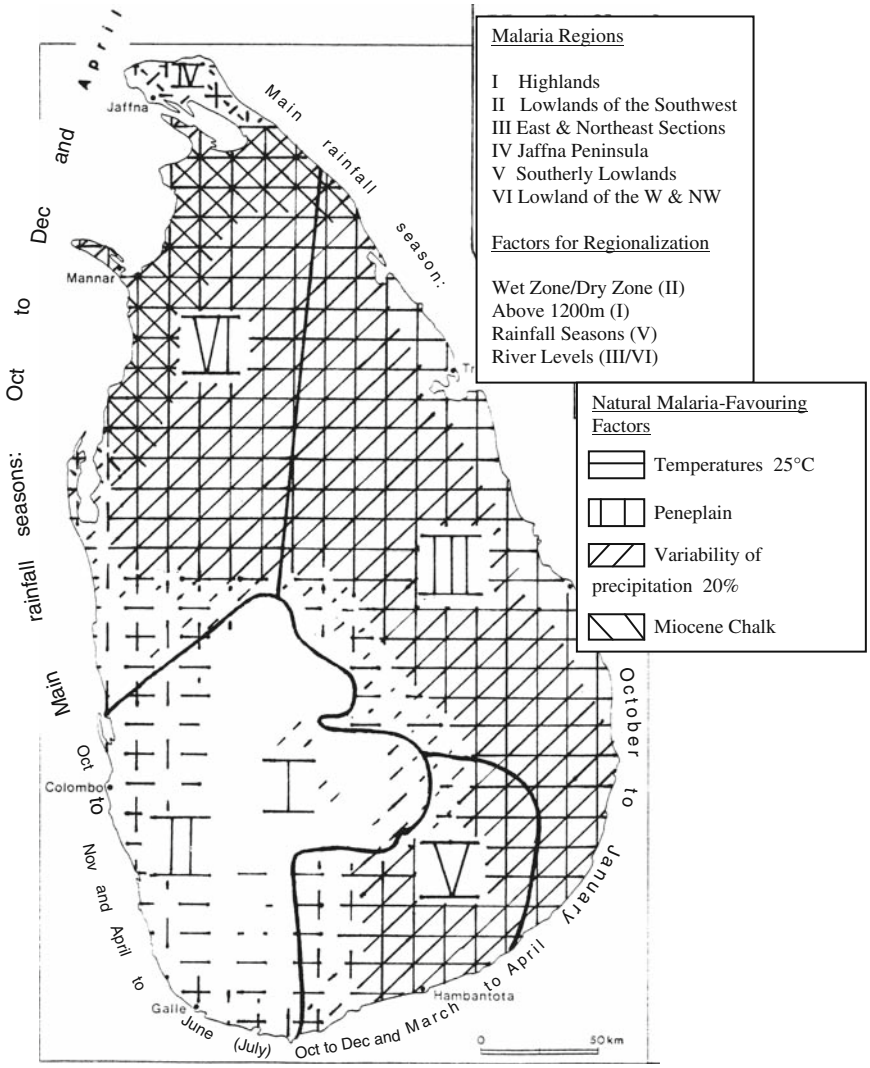


Fig. 3.8 Ecological topography of malaria in Sri Lanka

Zone. The medical treatment of commuters, pilgrims, and other travelers should be undertaken with the aim of restricting malaria to the Dry Zone.

Outside the Wet Zone the situation reverses quickly, such that the risk of malaria is very high. Three factors exist in all areas of the Dry Zone: flatland with red loam formations, tropical lowland temperatures (above 25°C/46°F), and the unreliability and variability of the precipitation (over 20% variability), all of which are conducive to malaria incidence. In addition, the thinner distribution of vegetation means that

more waterholes and sources are exposed to the sun, and can become favorable breeding places for the *Anopheles* (Fig. 3.8).

The Dry Zone can be topographically differentiated in terms of malaria potential, given the differences in levels of precipitation, the river system, and the filling of tanks. The East and Northeast sections (Area III) are exposed to the Northeast monsoon and receive the highest level of precipitation in the Dry Zone. This takes place almost without exception between October and January. During this period flooding occurs constantly, cutting off smaller water sources. Tanks and hollows in the ground fill up with water, and the swampy areas, particularly in the Mahaweli Ganga district, form stagnant water pools. Such a large number of conducive breeding grounds for the *Anopheles* provide excellent conditions for malaria epidemics to fully develop here from November onward. Widespread desiccation of water sources, with high potential evaporation rates and lower humidity values make the yearly mean outside the rainy season appear less dangerous. However, the geomorphous influence of cut-off seaside lakes and the drawing power of pilgrim centers such as Trincomalee and Polonnaruwa must be considered in the local impact. In addition, lack of hygiene in the towns leads to localized malaria incidence. The tendency toward the practice of the *Chena* farming in this area of Sri Lanka also increases the risk of malaria.

Toward the north, the level of precipitation and its reliability diminishes, while maximum potential evaporation rates are reached. As a result, the perennial water surfaces are quickly reduced to single puddles so that this region, due to its inherent natural characteristics, turns into a very high-risk area as regards malaria infection. This is particularly true of Mullaitivu and Kilinochchi, since the coastal formation here favors the creation of cut-off seaside lakes. The nature of the miocene chalk subterrain layers also means an increase in the risk level in the North, where the numerous water-filled holes are ideal mosquito breeding places. However, the absence of the *Chena* practice in the Tamil inhabited area and the low population density contribute toward keeping the malaria risk from increasing any further.

On the basis of physio-geographical malarial factors, the northerly connecting Jaffna peninsula (Area IV) must be considered just as much at risk as the neighboring mainland. The densely populated Hindu pilgrim centers in Jaffna increase the malaria risk even further. However, the intensive field cultivation plays an important inhibiting role, with the result that this area has the second lowest level of malaria in Sri Lanka.

In many aspects, the southerly Lowland (Area V) parallels the situation in the northerly section, where very low and unreliable precipitation levels in conjunction with a high potential evaporation rate give rise to a tendency for water to constantly reduce to isolated puddles and pools. This results in a year-round high malaria risk. The situation is dramatically inflamed by the drawing power of the religious centers of Kataragama in this area of the Dry Zone, and by the practice of *Chena* land burning, which favors the spread of malaria. However, low population density reduces the danger of infection to some degree. In areas directly exposed to the Northeast monsoon, increasing monsoon precipitation in March and April results

in intermonsoon peaks that add to the expected Northeast monsoon precipitation levels—a characteristic that differentiates the southern region from the southeast.

The latter aspect of intermonsoon peaks is also valid for the Westerly and Northwesterly (Area VI) part of the Dry Zone. Fluctuation of water levels in rivers and tanks in line with the rhythm of the rainy season is usually expected to cause greater malarial risk. However, due to the better surface water drainage caused by higher and more reliable yearly precipitation and a more favorable water balance, the southern parts of Area IV do not reach the same high level of infection intensity as Hambantota. At the same time, *Chena* rice cultivation technique and the places of pilgrimage here keep malaria risk from dropping to a low categorization. Lastly, an increase in malaria risk is caused by the formation of seaside lakes along the entire coastline, and by the presence of *karst* waterholes (typical morphologies in limestone rock areas) in Northwest Sri Lanka.

Conclusions for the Malaria Campaign

If malaria is to be eradicated from the Dry Zone, then the malaria campaign must be based on the factors identified in this chapter. The new development of agricultural land in the Dry Zone with the consequent reduction and elimination of malaria appears to be a valid approach toward malaria containment. A synchronized or independent chemical/biological/genetic campaign against the *Anopheles* might not systematically or simultaneously encompass the whole Dry Zone, but should be carried out with respect to the locally developed malaria regime, topography, and intensity level. It appears promising to spray houses within the most endangered districts as well as the temporarily accumulated waters resulting from the rainy season. In accordance with the water level data reported by the Irrigation Department, small water hollows should be filled in, while larger water collection points should be drained or sprayed. In perennial water points, larva eaters could be used.[5] Regulations pertaining to the tending of abandoned *Chena* by the previous user would also be useful. The areas of Alarm Levels 1 and 2 in the various malaria topographies must be handled with particular care in order to prevent malaria from breaking out into epidemic proportions in the first instance. Registered water levels can be used as the determining instrument of combative measures in almost all districts, but this is insufficient in the unpredictable and stubborn north and south malaria centers. Here, continual awareness is required. In the other malaria centers, the principle of concentrating all efforts on the comprehensive elimination and control of malarial factors in their seasonal rhythm can be applied as prioritized by the level of importance of the district in causing malaria outbreaks.

Even if the spraying programs in the Dry Zone yield short-term results, they must remain in the foreground because of their purely systematic uses. It is more promising to use the principles of malaria control toward achieving its eradication. To this end, the establishment of a warning system appears worthwhile. This could be set up in the Control Areas. The Malaria Centers and transmission routes are also suitable for experimentation and research, wherein the observation and recording of

the number of *Anopheles* in monthly or shorter periods, and a census of the available feeding, breeding, and resting places could be done. The effectiveness of larva eating fish could also be evaluated here. The personnel required could be made available by the achievement of cost savings in other less malaria-prone areas, as mentioned before, because the intensive tending of the Control Areas reduces the risks in the remaining areas.

Furthermore, cooperation between Sri Lanka's Anti-Malaria Campaign and the Irrigation Department would be very useful, since future trends of malaria incidence could be forecast from the evaluation of the daily recorded water levels. On this basis, spraying and other actions that usually begin before the expected breakout of the monsoon in the Dry Zone could be effectively directed and carried out.

The sequence of measures in the individual areas can thus be carried out with respect to the now established facts and consequent classification levels of areas. These can inhibit the usual path of the progression of malaria toward its epidemic peak. This sequence of measures is more important than spraying, which only affects resting adult *Anopheles*. It is more important to fill in smaller water bodies, and above all, treat larger water areas with sealing oils in order to prevent the *Anopheles* larvae from respiring. If this is limited even to the control areas, then it is conceivably possible to treat all water sources with a nontoxic organic film in time, and kill all larvae present. Given the short life span of the *Anopheles*, several short-term interruptions of the larvae redevelopment would be sufficient to decimate the mosquito population to a great extent.

As a supplementary measure, antimalaria medication should be issued to all inhabitants in order to prevent new infections and to alleviate acute cases. The malaria patients of the last few years should be regularly examined to check for any parasites present in their blood. In the case of reaffliction, they should be treated in mosquito-free hospitals (equipped with mosquito nets, fans) in order to avoid further transmission of the infection.

Next to the development of resistance by the *plasmodia* and *Anopheles* to the preventive and curative measures, the particular risk to attempted eradication is the decreasing immunity of the population, which is a direct result of a continual low rate of infection. The closer one comes to achieving the aim of complete eradication, the greater the danger of a catastrophic epidemic. Awareness must therefore be maintained constantly and consistently.

The analysis indicates another method of controlling malaria; the regulated cultivation of the Dry Zone through year-round irrigated tillage. This would necessitate the excavation of deep-water reservoirs and the possibility of flushing out the entire flow system on a weekly basis, or more frequently. The simple replenishment of old tanks would not suffice. The inhabitants could be persuaded to give up the practice of the malaria-promoting *Chena* cultivation technique in favor of development projects, which in turn could become a magnet for high population concentrations. Areas in the Dry Zone, undeveloped by dam projects, could be abandoned as settlement and farming areas. In this way, malaria-free or low infection-rate islands could be created (as Jaffna is today), and the land in between would remain mosquito plagued but free of human habitation. Theoretically, this would result in the

elimination of malaria. This method would attack the problem at its root but could only be practically realized over a long period of time, and with much testing over time. In conclusion, the outlook for the eradication or at the very least, control and prevention of malaria in Sri Lanka is very positive.[6]

Notes

1. This chapter is an extract from the author's dissertation: Peters, G. (1982), Malaria in Sri Lanka – eine geomedizinische Analyse, 305 pages, Dissertation, Johannes Gutenberg Universität Mainz, Mainz, Germany.
2. Editors' note: Spleen index is calculated by multiplying the transverse diameter of the spleen by its longitudinal diameter. The index varies by age and body size of the person, but on average, the index will be higher in a person with malaria due to the enlargement of the spleen caused by the disease.
3. Editors' note: Miocene chalk is a type of limestone that dates back its formation to the Miocene geological period approximately 6–23 million years ago. According to the (US) Library of Congress Country Studies data site, this type of soil is found in the northwestern region of Sri Lanka, mainly along the coast (Sri Lanka: Geology, updated October 1988, retrieved May 26, 2009 from http://lcweb2.loc.gov/cgi-bin/query/r?frd/cstdy:@field(DOCID+lk0052).
4. Malaria intensity measured by the number of newly registered cases of malaria as a function of the size of the population per health area.
5. Editors' note: For more information on vector management and control in Sri Lanka, see Chapter 10.
6. Editors' note: The study was conducted and the analysis written independent of the influence of ethnic conflicts in Sri Lanka, which have disrupted various efforts and programs on several occasions. With the possible end of this conflict in sight at the time of publication, it is highly likely that Sri Lanka will be able to spend even more time and resources on malaria control efforts that have already seen some success here. See Chapter 10 for the present situation in Sri Lanka regarding malaria occurrence and control efforts.

References

Briercliffe R., Dalrymple-Champneys W and Wigglesworth V.B. (1936), 'Discussion on the malaria epidemic in Ceylon 1934–35,' *Proc R Soc Med*, 29: 537–562.

Carter H.F. (1927), *Report on Malaria and Anopheline Mosquitoes in Ceylon*, Sessional Paper Nr. VII, Government Record Office, Colombo.

Dickson R.M. (1935), 'The Malaria Epidemic in Ceylon, 1934–35,' *J R Army Med Corps*, 65: 85–90.

Domrös, M. (1974), Die Bedeutung bioklimatscher Untersuchungen für geomedizinische Forschungen. In H.J. Jusatz, Fortschritte der geomedizinischen Forschung. Beiträge zur Geoökologie der Infektionskrankheiten. Erdkundliches Wissen 35: 142–149.

Domrös M. (1976), 'Sri Lanka—die Tropeninsel Ceylon,' *Wissenschaftliche Länderkunden*, Vol. 12, Darmstadt.

Ellison, F.O'B. (1936), 'Malaria Epidemics and Sun-Spot Cycles,' *Trans R Soc Trop Med Hyg*, 30: 659–665.

Gill, C.A. (1936a), 'Some Points in the Epidemiology of Malaria Arising Out of the Study of the Malaria Epidemic in Ceylon in 1934–35,' *Trans R Soc Trop Med Hyg*, 29: 427–480.

Gill, C.A. (1936b), 'The Mode of Onset of the Malaria Epidemic in Ceylon,' *Trans R Soc Trop Med Hyg*, 30: 101–107.

Gsell, O.R. (1972), Die Infektionskrankheiten: Durch Prophylaxe und Therapie zur Eradikation. In. Pathomorphosis 1. Basle.
Indrapala, K. (Ed.) (1971), *The Collapse of the Rajarata Civilization in Ceylon and the Drift to the South-West*. Symposium Ceylon Studies Seminar, University of Ceylon, Peradeniya.
James, S.P. (1935), '*L'épidemié de Paludisme à Ceylan* en 1934–35,' Bull Off Int Hyg Publ, 27: 1135–1140.
Jusatz, H.J. (1966), 'The Importance of Biometeorological and Geomedical Aspects in Human Ecology,' *Int J Biometeorol*, 10: 323–334.
Learmonth, A.T.A. (1979), 'Die Wiederkehr der Malaria in Indien 1965–1976,' *Geomedizin in Forschung und Lehre*, Erdkundliches Wissen 51: 29–41.
MacDonald, G. (1957), *The Epidemiology and Control of Malaria*. London: Oxford University Press.
NMCO (1973), *Administration Report of the Anti-Malaria Campaign for the period October 1971 to December 1972*. Colombo: Directorate of the Ministry of Health.
National Malaria Control Office (1976), *Administration Report of the Anti-Malaria Campaign for the year 1976*. Colombo: Directorate of the Ministry of Health (DMH).
NMCO (from 1974 to 1981), *Administration Report of the Anti-Malaria Campaign for the years 1973–1980*. Colombo: Directorate of the Ministry of Health.
Nauck, E.G. (1958), *Die Ausrottung der Malaria als Aufgabe der Internationalen Forschung*. Hamburg.
Nauck, E.G. (1975). W. Mohr, H.H. Schumacher, F. Weyer (eds.). *Lehrbuch der Tropenkrankheiten*. Stuttgart: Thieme.
Peters, G. (1982), *Malaria in Sri Lanka – eine geomedizinische Analyse*, Dissertation, Johannes Gutenberg Universität Mainz, Mainz, Germany, p. 305.
Rodenwaldt, E. (1937), 'Die Malariaepidemie auf Ceylon 1934/35 als Geomedizinisches Problem,' *Koloniale Rundschau*, 28: 330–344.
Service M.W. (1976), *Mosquito Ecology: Field Sampling Methods*. New York: Halsted Press.
Schilling, C. (1936), 'Die Malariaepidemie auf Ceylon 1934/35,' *Archiv Für Schiffs – und Tropenhygiene*, 40: 51–63.
Weise, H.J. (1974), 'Malaria-einschleppungen in die Bundesrepublik Einschl. Berlin (West) während der letzten 10 Jahre (1963–1972),' *Deutsche Medizinische Wochenschrift*, 99: 966–975.
Weyer, F., F. Zumpt (1966), *Grundriss der Medizinischen Entomologie*. Leipzig: J.A. Barth–Verlag.
WHO (1957), 6th Report of the Expert Committee on Malaria. *WHO Technical Report Series*, No 123.
WHO (1965), Nutrition and Infection. Report of a WHO Expert Committee. *WHO Technical Report Series,* No. 314.
WHO (1969), Parasitology of Malaria. Report of a WHO Scientific Group. *WHO Technical Report Series,* No. 433.
WHO (1972), Vector Ecology. *WHO Technical Report Series,* No. 501.
Wigglesworth, V.B. (1936), 'Malaria in Ceylon', *Asiatic Review* 32: 611–619.

Chapter 4
Malaria Resurgence in Nepal: An Overview

Bishnu Dev Pant

Abstract This chapter provides a brief overview of the malaria situation in Nepal in the mid-twentieth century and proceeds to assess the characteristics of malaria resurgence in Nepal during the 1970s and early 1980s. Topographically, the Himalayan nation of Nepal (an erstwhile kingdom) is divided into four strata, namely the Southern plain (*Tarai*) area, Churia/Shivalik range of Hills, Mahabharat range of Hills, and the Himalayan range. Antimalaria activities are typically carried out in the *Tarai*, Inner *Tarai* (valley between Churia and Mahabharat range), and in the Hills rising up to 4,000 ft (approximately 1,220 m) (Fig. 4.1). In total, 52 districts[1] have been covered since the beginning of antimalaria activities.

Keywords Malaria vectors · Nepal · Malaria parasites

Incidence of Malaria in Nepal

Prior to the initiation of antimalaria activities in the mid-1950s, Nepal had an estimated two million cases of malaria annually, with 10% of the patients dying of the disease (USAID/Nepal 1980). Organized antimalaria activities began in 1958 after the establishment of the Nepal Malaria Eradication Organization (NMEO). Prior to this, two pilot projects had been initiated in 1954 for this purpose. By 1965, the NMEO was able to establish and operate an effective nationwide antimalaria effort that resulted in large areas being freed of the ravages of malaria. The sharp reduction of the disease resulted in large-scale settlement and resettlement of formerly malarious areas of the *Tarai*, Inner *Tarai*, and the forest fringe. The progress remained satisfactory until the year 1970, which recorded amongst the lowest numbers of malaria cases since the initiation of the malaria eradication program in the

B.D. Pant (✉)
South Asian Institute of Management (SAIM), and Director, Centre for Economics and Applied Statistics (CEAS), SAIM, Kathmandu, Nepal
e-mail: bishnu.pant@gmail.com

R. Akhtar et al. (eds.), *Malaria in South Asia*, Advances in Asian Human-Environmental Research 1, DOI 10.1007/978-90-481-3358-1_4,

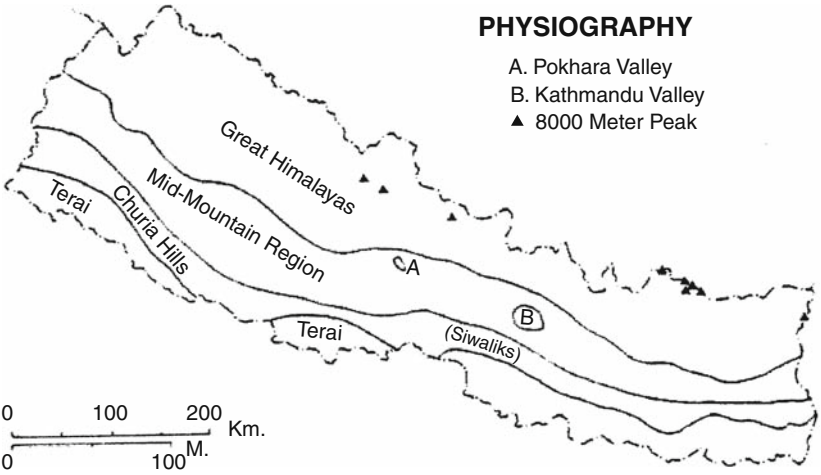


Fig. 4.1 Physiography of Nepal
Source: Dutt and Gieb 1987, p.212.

country, as shown in Table 4.1(NMEO 1972). About 91% of the entire *Tarai* area that was originally hyperendemic was shifted from the initial "attack" phase to the "consolidation" phase within this period (NMEO 1980).

Malaria cases began to reappear in 1971, first observed in western *Tarai*, and later in central *Tarai* area by 1973. Since then, malaria cases gradually increased and peaked in 1982, then recorded a slight decline for the first time in 1983[2] (Table 4.2). Out of 16,719 total positive cases detected in 1983, the number of imported cases was 6,126 (36.64%). The proportion of imported cases, primarily from India, has been steadily increasing over the years, particularly since 1970. Obviously, the imported cases seem to have contributed significantly to malaria resurgence in Nepal. In fact, total malaria cases detected and the cases that were imported showed a positive correlation at a statistically significant level ($r = 0.93$; $p = 0.05$). The relationship between total malaria occurrence and imported malaria cases is depicted in Fig. 4.2.

Table 4.1 Malaria incidence in Nepal, 1966–1970

Year	Total slide collection	Total positive case detection
1966	554,973	8,583
1967	676,923	6,030
1968	776,934	2,464
1969	882,604	3,897
1970	1,002,134	2,518

Source: NMEO 1972

Table 4.2 Recurrence of malaria in Nepal, 1969–1983

Year	Total positive case detection	Total endogenous cases	Total exogenous cases	Percentage of exogenous cases to total positive (%)
1969	3,897	3,661	236	6.06
1970	2,518	2,063	455	18.07
1971	2,778	2,251	527	18.97
1972	4,067	3,077	990	24.34
1973	8,479	7,078	1,401	16.52
1974	14,647	11,506	3,141	21.44
1975	12,372	8,764	3,608	29.16
1976	10,123	6,570	3,553	35.10
1977	11,972	8,666	3,306	27.61
1978	13,898	10,233	3,665	26.37
1979	12,992	9,081	3,971	30.10
1980	14,148	10,658	3,490	24.67
1981	16,085	12,256	3,829	23.81
1982	16,907	12,113	4,794	28.36
1983	16,719	10,593	6,126	36.64

Source: NMEO 1983

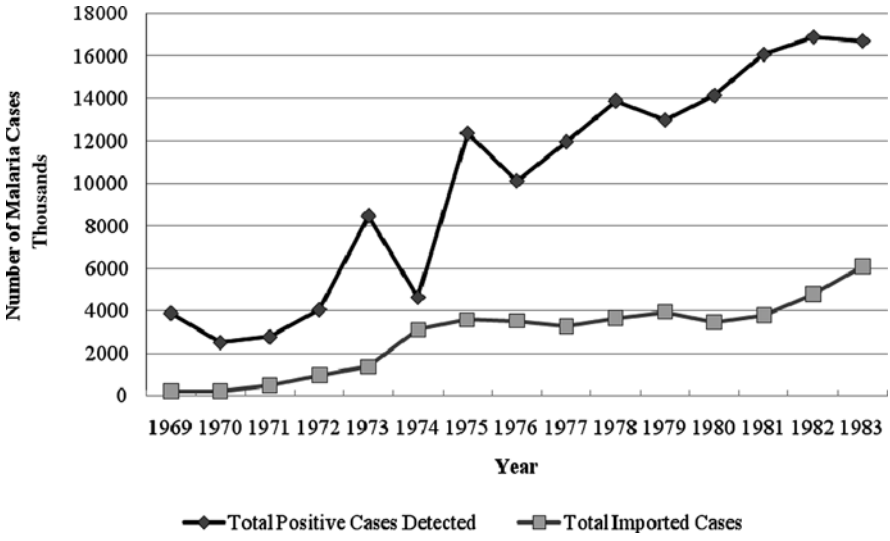


Fig. 4.2 Total malaria incidence and imported cases in Nepal
Source: Prepared by author based on NMEO 1983.

Agents of Malaria in Nepal and the Malaria Parasite

The parasites that cause malaria and the vectors that carry them are extremely pertinent to understanding the malaria situation in Nepal. They are discussed in the section below.

Malaria Vectors

On examining the distribution pattern of main vector species in Nepal, it is found that *Anopheles annularis* is the most prevalent and dominant vector in the country, followed by other vectors such as *Anopheles fluviatilis*, *Anopheles maculatus*, *Anopheles culicifacies*, *Anopheles subpictus*, *Anopheles vagus*, *Anopheles sinesis*, *Anopheles aconitus*, and *Anopheles niggerrimus.* The vector *A. annularis* was first incriminated in 1972 in some areas of Lumbini Zone. A later study conducted in the district of Parsa also proved that *A. annularis* was responsible for low-grade malaria transmission in the area. A number of other studies conducted in various areas confirm that this particular species was quite dominant in the remaining *Tarai* areas, and even in the hills and mountain valleys up to an altitude of 6,500 ft (1,981m) (see Shrestha and Parajuli 1980). Susceptibility tests conducted in the areas of *A. annularis* abundance showed that the species was highly resistant to DDT, had intermediate resistance to Dieldrin, but susceptible to Malathion (White 1982).

The impact of DDT spraying was seen to be satisfactory in most areas, except in the northern belt of Dhanusha, Mahottari district and Dang districts, where malaria incidence was on the increase in spite of regular DDT application. Vectors such as *A. fluviatilis* and *A. maculatus* were also found to be very active in the transmission of malaria in the country. It is suspected that *A. maculatus* being an early-night biter, outdoor biter, and rester, is responsible for the deterioration of the situation. Both vectors, *A. fluviatilis* and *A. maculatus*, were found susceptible to DDT; the record of *A. fluviatilis* in sprayed premises shows that the infection rate in such areas is remarkably low compared to unsprayed premises (see White 1982).

Malaria Parasites

Prevalence of *Plasmodium falciparum* (a lethal malaria parasite) infection was predominant in the hyperendemic belt of the country before the malaria eradication program was launched. With the launching of an antimalaria campaign, *Plasmodium Vivax* gained momentum, and this situation has prevailed until now. However, the incidence of *P. falciparum* infection has shown a fluctuating pattern during the 15-year period (1969–1983) of this study. The highest incidence of *P. falciparum* infections was recorded in 1975, at 25% of total cases. At this time, the incidence of indigenous *falciparum* infections was around 9% (Parajuli 1985).

During the last few years of the twentieth century, the incidence of *falciparum* infections gradually declined in the eastern region, but slowly rose in the central and western regions. Moreover, the mid- and far-western regions recorded a sharp rise in malaria cases. It should be noted that malaria epidemics had reportedly occurred in some of the districts in the state of Uttar Pradesh in India (Learmonth and Akhtar 1977) that are adjacent to the districts of mid- and far-western regions of Nepal. Therefore, the shifting pattern of *P. falciparum* infections toward the mid- and far-western regions might perhaps be attributed to the movement of population to and from the districts of Uttar Pradesh (India), where *P. falciparum* infections are prevalent.

It was observed that compared to indigenous cases, the imported *falciparum* cases were not responding adequately well to the conventional malaria treatment. A field study was carried out to estimate the preponderance of the drug-resistant strain of *P. falciparum* among the imported cases, and a large number of these cases were confirmed to be resistant to chloroquine (Parajuli 1985).

Resurgence Characteristics and Causes

Regional Distribution

Of the total malaria cases recorded in the country during 1981–1982, it was found that 60% of them occurred in the nine *Tarai* districts alone. These districts are Sarlahi, Mahottari, Dhanusha, Rautahat, Bara, Parsa, Nawal Parasi, Rupandehi, and Kapilvastu, where *A. annularis* has been suspected to be the main vector responsible for the transmission of malaria. Further breakdown of the cases reveals that there was a decline in malaria cases in the eastern regions, while increases had been noticed in the western regions, particularly in the far-western area (NMEO 1983). In view of the increasing incidence of malaria, a comparison of the annual parasite index (API) by districts over two points of time has been made. The APIs for the years 1976 and 1982 were mapped for this comparison (Figs. 4.3 and 4.4). On the basis of the APIs, four categories or classes of malaria intensity emerged, as shown in Table 4.3.

As compared to 1976, malaria incidence had increased in 1982. In 1976 there were only seven districts falling in the "Very High" category. During the 6-year period, the number of districts falling into this class rose to 13. Similarly, although there was a significant decline in the number of districts falling in the "High" category, the districts falling in "Medium" class recorded a slight increase. The number of districts falling in the "Low" class also declined from 3 in 1976 to 1 in 1982, revealing that a greater number of districts had shifted to higher API categories in 1982 as compared to 1976.

At both points in time, most of the "High" values occurred in the *Tarai* districts bordering India. Additionally, the "High" value districts falling in western regions of Nepal displayed a tendency to move up toward the "Very high" value group over

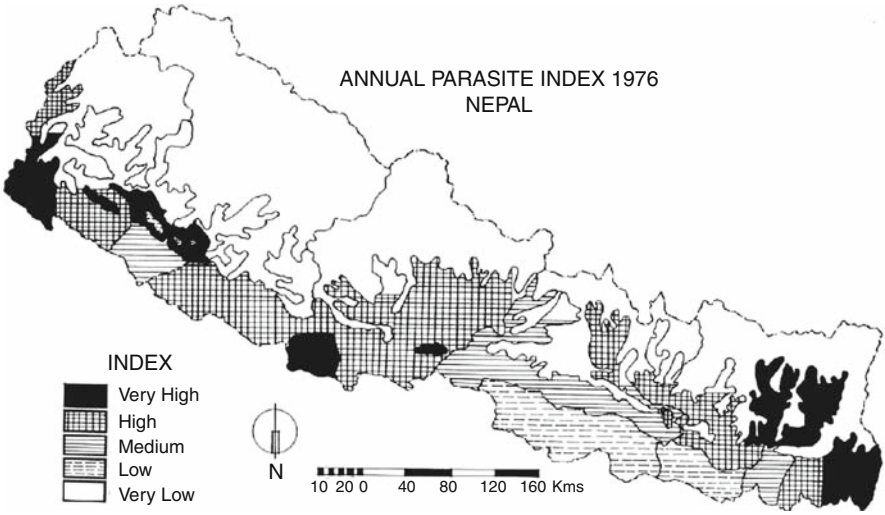


Fig. 4.3 Annual parasite index in Nepal, 1976
Source: Prepared by author based on NMEO 1983.

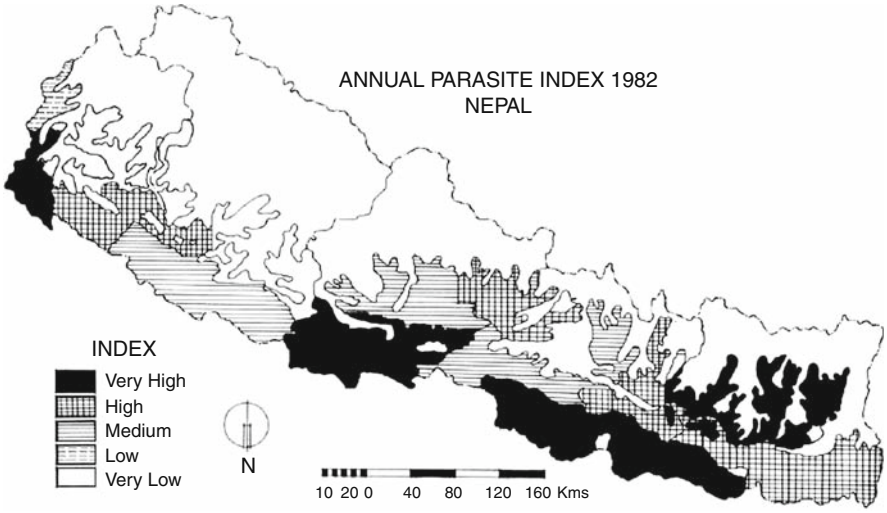


Fig. 4.4 Annual parasite index in Nepal, 1982
Source: Prepared by author based on NMEO 1983.

the 6-year span, indicating that the movement of people to and from neighboring Indian districts might have contributed to the significant increase in total malaria cases in these districts. Also, some of the hilly districts recorded an increase in API values between 1976 and 1982. This implies that enough attention had not been paid to the control of malaria in these districts.

Table 4.3 Distribution of categories of annual parasite indexes: Nepal, 1976 and 1982

	Number of districts falling in the class				
Year	Very High (VH) >2.0	High (H) 1.0–2.0	Medium (M) 0.5–1.0	Low (L)< 0.5	Total no. of districts
1976	7	15	6	3	31
1982	13	10	7	1	31

Factors Causing Malaria Resurgence

A number of factors could be responsible for malaria resurgence in the country. They are: population density, cultivated land, irrigation intensity, cropping intensity, rainfall, number of migrants, resettlement in newly cleared forest areas, and construction and repair of canals and roads. It is interesting to study the relationship these variables may have with the API, and to examine which of these are most important in contributing to the resurgence of malaria in Nepal. It is not possible to examine all of these relationships in this chapter. However, an attempt has been made to study the relationship between APIs and two physical variables (rainfall and irrigation intensity) and two demographic variables (population density per unit of geographical area and population density per unit of cultivated area).

No statistically significant correlation was found between API and rainfall, and between API and irrigation intensity. This might simply be because of the dubious nature of data on rainfall and irrigation intensity. A similar lack of relationship exists between API and population density per unit of cultivated land or physiological density. However, a statistically significant correlation coefficient of 0.52 was found between API and population density (1981) per unit of geographical area. Therefore, it implies that in areas of high population density, such as the *Tarai* districts, transmission of malaria may be rapid, and immediate attention should be targeted to such target areas.

The quantitative relationship between the APIs and resettlement activities could not be tested or established because of the unavailability of adequate resettlement data. However, it can be fairly safely assumed that resettlement activities in the forested *Tarai* area, particularly activities that are unauthorized, might result in the appearance of focal malaria outbreaks among these settlers who are usually difficult to pin down to a permanent settlement and so cannot be served by regular health personnel. Similarly, the laborers involved in the construction of roads, canals, and embankments may play an important role in causing malaria resurgence in the country due to their mobility. The disease may easily pass unnoticed to the villagers among whom the temporary laborers reside, until the infection appears in the neighboring settled villages they had been before.

Other causes for malaria resurgence are shallow earth wells, ponds of all kinds including borrow-pits and cut-offs, and flooded fallow fields—all are important breeding places that multiply greatly during the heavy monsoon season. In the *Tarai*

area where the occurrence of malaria is high, these breeding places account for great increases in malaria incidence.

Strategy for Malaria Control

The increasing incidence of malaria cases in the country brought about a realization for concerted efforts to check this disease. The 6th Five-Year Plan prepared by the Nepal Planning Commission (NPC 1980) targeted a population of approximately 6.4 million persons to be covered by the antimalaria activities. It was proposed that by the end of the plan period, the incidence of malaria would decline to 1 per 1,000 of population. To achieve this objective, both insecticidal and surveillance activities were intensified. Active case detection, epidemiological investigation and classification of malaria cases, radical treatment and other focal measures,[3] and the follow-up of every case for 1 year were the main features of the surveillance operations (NPC 1980).

In most of the districts of the country, particularly the *Tarai* districts where *A. annularis* had been found resistant to DDT, the alternate insecticide Malathion was introduced to combat the incidence of malaria. Based on the epidemiological situation, DDT was sprayed in moderate-receptive areas of all the regions, and low-receptive areas of the mid-western and eastern regions (see White 1982).

The imported *falciparum* parasite that had been resistant to the chloroquine treatment was subjected to the more effective radical treatments. Similarly, surveillance activities were expanded to include the malaria-free but receptive areas that remained susceptible to infection through continuous internal movement of the population.

Summary and Conclusion

The achievements of the malaria eradication program in the country since the 1960s were seen as a success before the resurgence of the disease began. The antimalaria activities were mainly concentrated in the accessible areas, particularly along the *Tarai* belts, and were very limited in less accessible parts of the country. The influx of cases from India, and the continuous internal movement of the population have diminished the hope for an easy victory over the disease. The malaria eradication program in the country is based on the principles of interruption of malaria transmission through insecticide application, and on the elimination of the reservoir of infection cases through surveillance activities. Therefore, continuous "alertness" and "watchfulness" toward this disease is needed in order to detect and speedily eliminate any malaria cases before the mosquito vectors in the highly receptive areas can propagate them (NMEO 1982).

New tactical approaches must be developed in conducting the long-term national malaria eradication program. These need to be based on the liberalization of certain epimediological criteria to enable the future phasing of entire units working in the attack phase areas into the consolidation phase areas. Considering the limited

impact of Malathion on malaria incidence in low caseload areas as compared to high caseload areas, it is desirable that efforts be made toward prompt detection and treatment of malaria cases, environmental manipulation to check vector breeding, and other appropriate methods to control malaria.

Keeping in mind the abundance of the vector *A. fluviatilis* in areas of low receptivity and the vector *A. maculatus* in areas of moderate receptivity, it is desirable that the role of these species in transmission of malaria in these areas be further investigated. Lastly, the measures presently adopted in controlling the incidence of malaria in the country do not seem adequate. Therefore, coordinated measures from different government agencies are called for in order to successfully control malaria incidence in the country.

Notes

1. The country is divided into five development regions, subdivided into 14 administration zones, and further divided into 75 political districts. Of the 52 districts where antimalaria activities were conducted, 40 districts were covered by the Nepal Malaria Eradication Organization (NMEO) and 12 districts by the Integrated Community Health Development Program (ICHDP).
2. Data is for NMEO districts. The districts in the years 1976 and 1982 are not exactly comparable and hence they should be cautiously interpreted.
3. Editors' note: Radical treatments refer to the effective treatment and total cure of confirmed cases to prevent relapse, e.g., treatment of chloroquine-resistant malaria with other drugs such as primaquine, which is gametocytocidal. Focal measures are actions targeted toward focal phenomena such as resistance and points of transmission, as opposed to dispersed phenomenon such as the multiplication and spread of resistant parasites.

References

Akhtar, R. and Learmonth, ATA (1977), "The Resurgence of Malaria in India 1965–76." *GeoJournal*, 1(5): 69–80.

Dutt, AK and Gieb, MM (1987), Fully Annotated Atlas of South Asia. Boulder, CO: Westview Press.

NMEO (1972), *Report of the Strategy Review Team on Malaria Eradication Program and the Development of Integrated Health Services in Nepal*. Kathmandu: Government of Nepal*, Ministry of Health.

NMEO (1980), *Malaria Eradication Program in Nepal: A Brief Review* (in Nepali). Kathmandu: His Majesty's Government of Nepal*, Ministry of Health.

NMEO (1982), *Plan of Action and Staffing Pattern for 1982/83*. Kathmandu: Government of Nepal, Ministry of Health.

NMEO (1983), *Situation Analysis Report 1982*. Kathmandu: Government of Nepal*, Ministry of Health.

NPC (1980), *The Sixth Five Year Plan, 1980/81–1984/85*. Kathmandu: Government of Nepal*, National Planning Commission, NPC Secretariat.

* The NMEO functioned under the monarchial government of Nepal (His Majesty's Government [HMG]) until 2008, when it was formally abolished.. it now functions under the Government of Nepal.

Parajuli MB (1985), "Report on Present Status of Drug Resistant Malaria in Nepal," *Meeting of Drug Resistant Malaria Studies* in SEAR 1985-89,WHO Regional Office, New Delhi, May 13–15.

Shrestha SL and Parajuli MB (1980), "Reappearance of Malaria in *Tarai* Area of Nepal and Incrimination of *A. annularis Van der Wulp*", *J Nepal Med Assoc*, 18(1): 11–18.

USAID/Nepal (1980), *Nepal Project Paper: Integrated Rural Health Family Planning Services*, No. 367-0135, Washington D.C.

White, GB (1982), *Malaria Receptivity Stratification and Projections for Malaria Vector Control in Nepal (SEA/MAL/144)*. Geneva: World Health Organization.

Chapter 5
Resurgence and Post-resurgence Periods of Malaria in Bangladesh

Ashok K. Dutt, Ishrat Islam, and Adrien Humphreys

Abstract Bangladesh has had a long history of malaria occurrence. During the British era, malaria mapping was first initiated by Bentley in 1916; the west central part of the country being moribund had the greatest concentration of malaria. Thereafter, during the Second World War large-scale anti-malaria activities were carried on using DDT. By the 1970s malaria incidents declined. It was wrongly thought that the disease has been eradicated. Malaria infected people from India, particularly Assam, and adjacent hilly areas brought the disease to Bangladesh, showing migration diffusion. By 1984, it was identified that there was a positive correlation between forested areas and high Annual Paradise Index areas. During the resurgence and post-resurgence periods the country was divided into several divisions based on convex growth pattern of malaria belying vector resistance to DDT and other insecticides.

Keywords Bangladesh · Malaria mapping · Anti-malaria activities · Migration · Malaria diffusion · Vector resistance

Bangladesh health administrators considered malaria to be one of the four leading health problems in 1975, but by 1985 this was no longer the case. The World Bank also reported that by the mid-1980s, there was an improvement in malarial morbidity in Bangladesh (Griffin 1992). During the colonial period and in the early 1950s, malaria was a pernicious public health problem in Bangladesh, particularly in rural areas where the agricultural economy was adversely affected because of large-scale morbidity (Kondrashin and Rashid 1987). Many fictional accounts reflecting reality were written about the misery caused by malaria in the villages.

Up until the end of the 1940s the cure for malaria was primarily based on quinine and related medicines. Most people considered a malaria episode as a fact of life and took it to be a matter of fate. Many lived with it, and those who were inflicted by the disease often accommodated their activities according to the fever

A.K. Dutt (✉)
Professor Emeritus of Geography, Planning and Urban Studies, University of Akron, Akron, Ohio, USA
e-mail: dutt@uakron.edu

R. Akhtar et al. (eds.), *Malaria in South Asia*, Advances in Asian Human-Environmental Research 1, DOI 10.1007/978-90-481-3358-1_5,

cycles caused by the malarial parasite. The colonial government attempted to control the disease as early as 1920 by distributing anti-malarial drugs and undertaking anti-larval measures (Kondrashin and Rashid 1987). An index map (Fig. 5.1) of the country indicates the pre-1985 district boundaries; they are now called "greater districts."

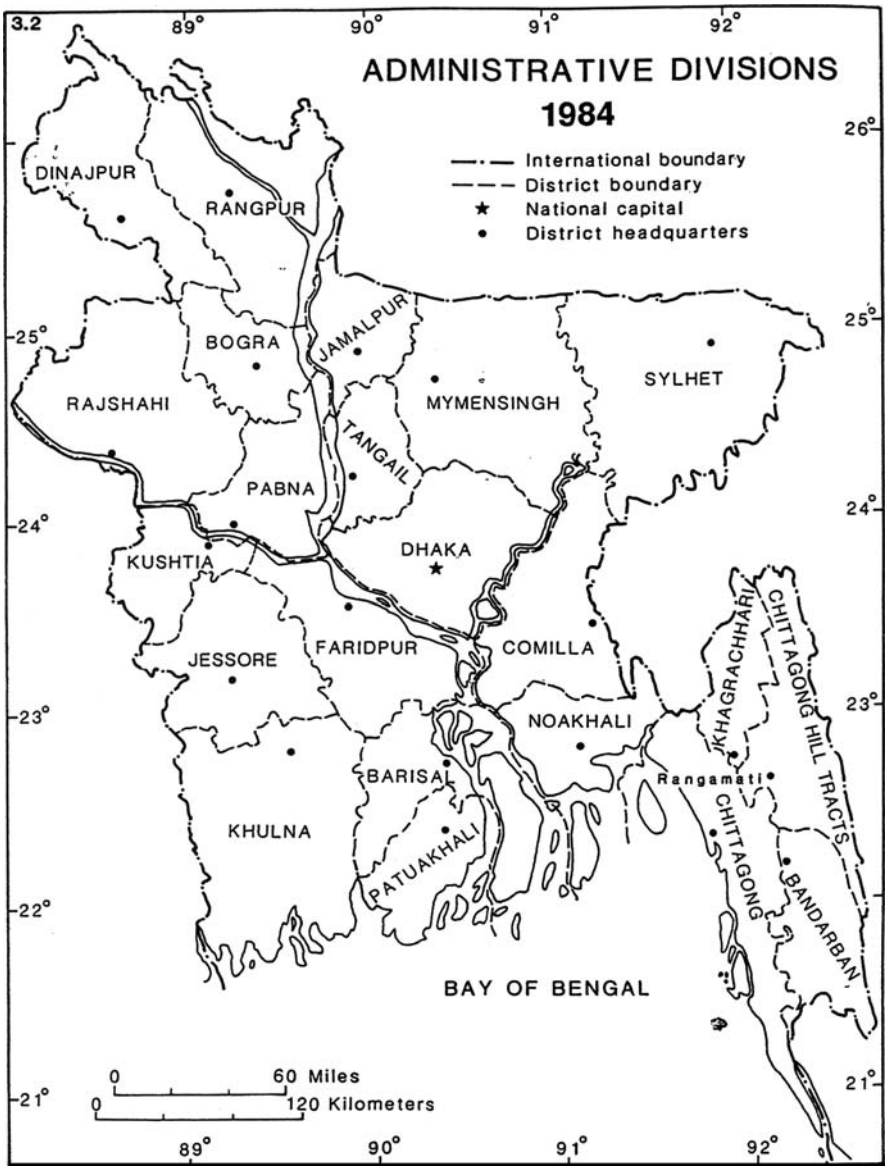


Fig. 5.1 District divisions of Bangladesh, 1984
Source: Dutt and Gieb 1996, p. 154.

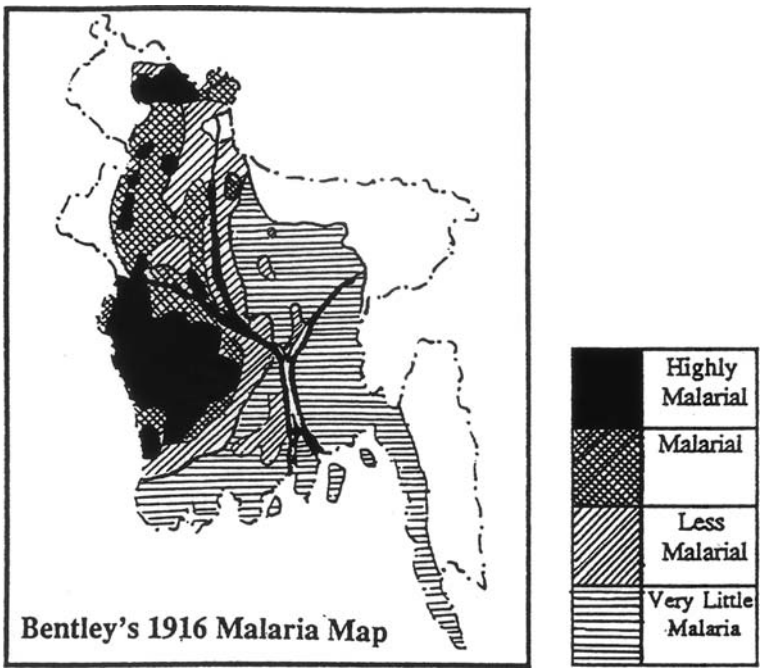


Fig. 5.2 Bentley's malaria incidence map of 1916
Source: Learmonth 1957, 51.

One of the finest works of assessing the spatial concentration of malarial episodes was done by Bentley (1916 in Learmonth 1957, 51) (Fig. 5.2). Bentley's 1916 map of malarial episodes can be understood in relation to Spate and Learmonth's (1967) division of Bengal and Bangladesh into physiographic subregions (Fig. 5.3.) A visual comparison of Figs. 5.2 and 5.3 clearly shows that the moribund Ganges delta (Fig. 5.3, VA), a good part of which falls in Bangladesh, displayed a high incidence of malaria in 1916.

A. philippinensis, also present in large numbers in the moribund delta, is the most common *Anopheles* species found all over Bangladesh, particularly in the plains. This vector is particularly prevalent in rice fields and is found both in houses and cattle sheds. In Malaysia, this vector prefers to feed on animals, although it sometimes also feeds on humans (Sandosham and Thomas 1983). In Bangladesh, however, a host preference study showed that 80% of this vector feeds on human beings and only 20% on animals (Kondrashin and Rashid 1987). This vector has a long flight range, and adults may fly in from breeding grounds situated a mile or more away (Sandosham and Thomas 1983). Though *A. philippinensis* is found throughout the year, it is particularly abundant during the period of rice growth from June to October. It is an open swamp breeder common in rice fields but also found in large and small "pools, drains, and streams" (Sandosham and Thomas 1983).

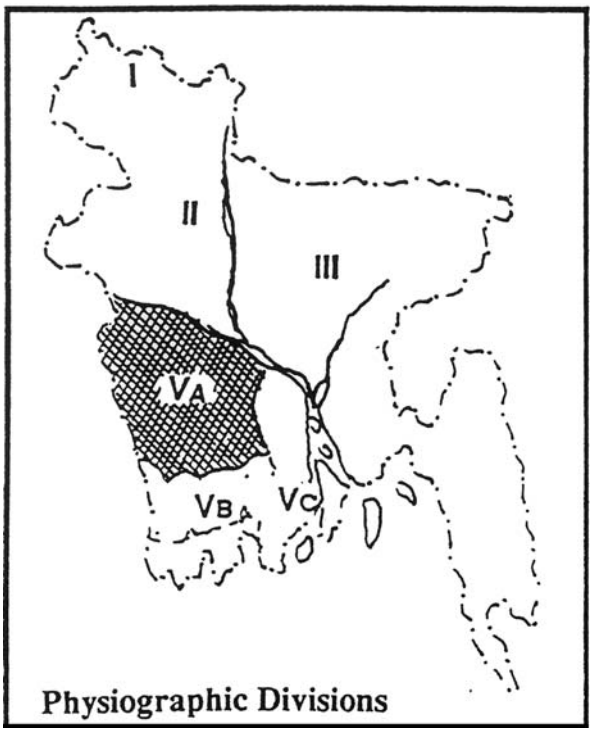


Fig. 5.3 Physiography of Bangladesh
Source: Spate and Learmonth 1967.

In the moribund delta the drainage of water is slow because the gradient is almost flat. Swamps and water reservoirs form during the rainy season, lasting June through November. Temperature-wise, all of Bangladesh is suitable for mosquito breeding throughout the year. Therefore, *A. philippinensis* has a conducive ecological base to thrive in the delta. As Bentley (1916, in Learmonth 1957) did not map the malarial incidence of Chittagong, Chittagong Hill Tracts, Banderban, and northeastern part of Bangladesh, the prevailing conditions of the disease in 1916 in those areas are not known as vividly as those in other parts of Bangladesh. Historically, as the ecology of Bangladesh changed with increasing population pressure, farming lands for rice cultivation were reclaimed from the swamps, thus providing a fertile ground for the breeding of the *Anopheles* mosquito. Almost all of Bangladesh had some malaria incidence during the colonial times, but the highest degrees of morbidity remained concentrated primarily in the western part of the country, which functioned as an endemic center for the eastward diffusion of this disease.

In the 1990s, malaria incidence in Bangladesh as a whole was not as severe as that in India, where the annual parasitic index (API)[1] reached 1.9% in 1992. This comparison is also very evident from the WHO data. Since 1963, the average API had gone up over 1.0% only once in Bangladesh and that was in 1992 (Fig. 5.4).

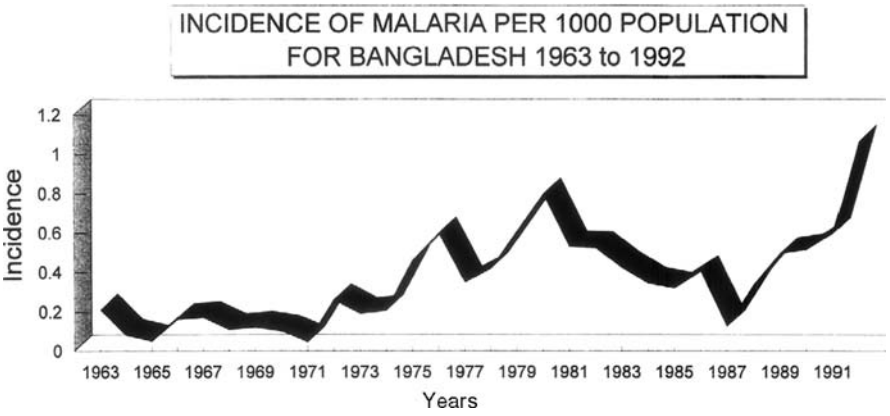


Fig. 5.4 Incidence of malaria per 1,000 population for Bangladesh, 1963–1992
Source: Calculated from data in: Kondrashin, and K.M. Rashid (ed.), 1987 and Statistical Yearbook of Bangladesh 1991, Dhaka: Bangladesh Bureau of Statistics.

However, the API trend showed a consistent rise during the 30-year period spanning 1963–1992 (WHO 1999).

During the Second World War, when a large number of allied troops were stationed in Bangladesh, anti-malarial activity included both anti-malaria drugs and insecticide spraying. These activities were primarily restricted to military bases and the places where military operations took place. The discovery of DDT did not necessarily lead to its immediate use as a means of vector control. In the beginning, as early as 1942, its use was restricted to killing human lice (Harrison 1978). Prior to the use of DDT, several less lethal chemicals (larvae oil, Paris Green, and Pyrethrum spray) were used to kill mosquito larva. In 1944, a trial run by the allied troops in Italy revealed that a single spraying of DDT could halt the transmission of malaria for the entire season, convincing the United Nations and the WHO that DDT was an effective answer for malaria control (Harrison 1978). In the 1950s, DDT spraying became common in Bangladesh. The WHO also began to fund anti-malarial activities, and by the 1960s, when it was found that the eradication of the disease seemed possible (as in India and other malaria-infected countries), Bangladesh also embarked on an eradication program. The result was a continuous decline in malaria incidence. Although the decline of API rates reached a low of 0.05 in 1971, malaria began to resurge thereafter, and the country's API continued to increase, albeit with some fluctuations in incidence. A full resurgence became evident in the early 1970s. Starting from 1987, the surge continued on through 1991 (Fig. 5.4).

Paul (1984) ascribes several reasons to the resurgence. First was the slackening of anti-malaria activity because of the significant reduction of malaria during the late 1960s. Second, the liberation war of the early 1970s interrupted the eradication program. Moreover, this period also witnessed the return of the refugees from the malaria-infected areas of India, such as Assam, Meghalaya, Tripura, and Mizoram, who brought the disease back in with them. Third, during the liberation

war, there was a large-scale destruction of homes forcing many to be homeless, living in the camps, and being exposed to mosquito bites. Fourth, the same war also caused destruction of livestock, causing the vectors to change their zoophilic habits. Fifth, a decline in the standard of living caused lesser calorie intake and lower nutrition levels, causing people to be less resistant to malaria. Per capita food production has consistently declined in Bangladesh from 1973 to 1993 (Dutt and Gieb 1996). The World Bank estimated that if the year 1987 is given an index value of 100, per capita food production in Bangladesh declined from 113.6 in 1973 to 103.7 in 1993 (World Bank 1995). Sixth, cultivation of high-yielding varieties of rice required extensive irrigated fields, helping expand mosquito-breeding reservoirs. Paul (1984) calls it a "change in man–environment relationship" (Paul 1984, 73). He also found that there was a close, positive, statistically significant relationship between acreage of high-yielding varieties (of crops) and incidence of malaria, and between forested area and incidence of malaria.

Paul (1984) cites the liberation war of 1971 as the prime reason for malaria resurgence in Bangladesh. In India too, the blame for resurgence was mostly placed on the Indo-Pakistan war of 1965. However, this is only partly true. The fact is that climatic conditions were ripe for malaria resurgence, both in India and Bangladesh, when the 1965 and 1971 wars expedited the process.

Paul (1984) also found a significant positive correlation between API rates and forested area. However, the fact remains that the most densely forested southern part of Bangladesh (Sunderban) had been, and still is malaria-free—compare Fig. 5.5 showing forested areas with Figs. 5.6, 5.7, and Fig. 5.8—infection rates have been on a sharp decline in these areas. But, it should also be noted that when malaria resurgence began in India after 1965, two of the three pockets that remained

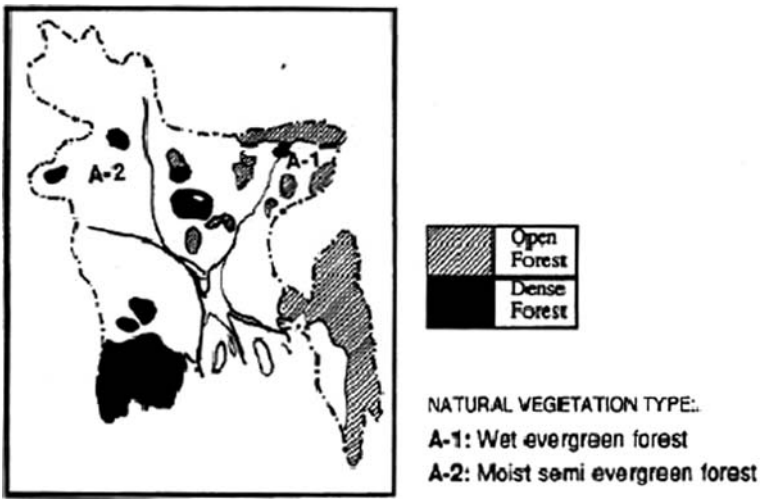


Fig. 5.5 Forested areas and natural vegetation types of Bangladesh
Source: Schwartzberg, 1992.

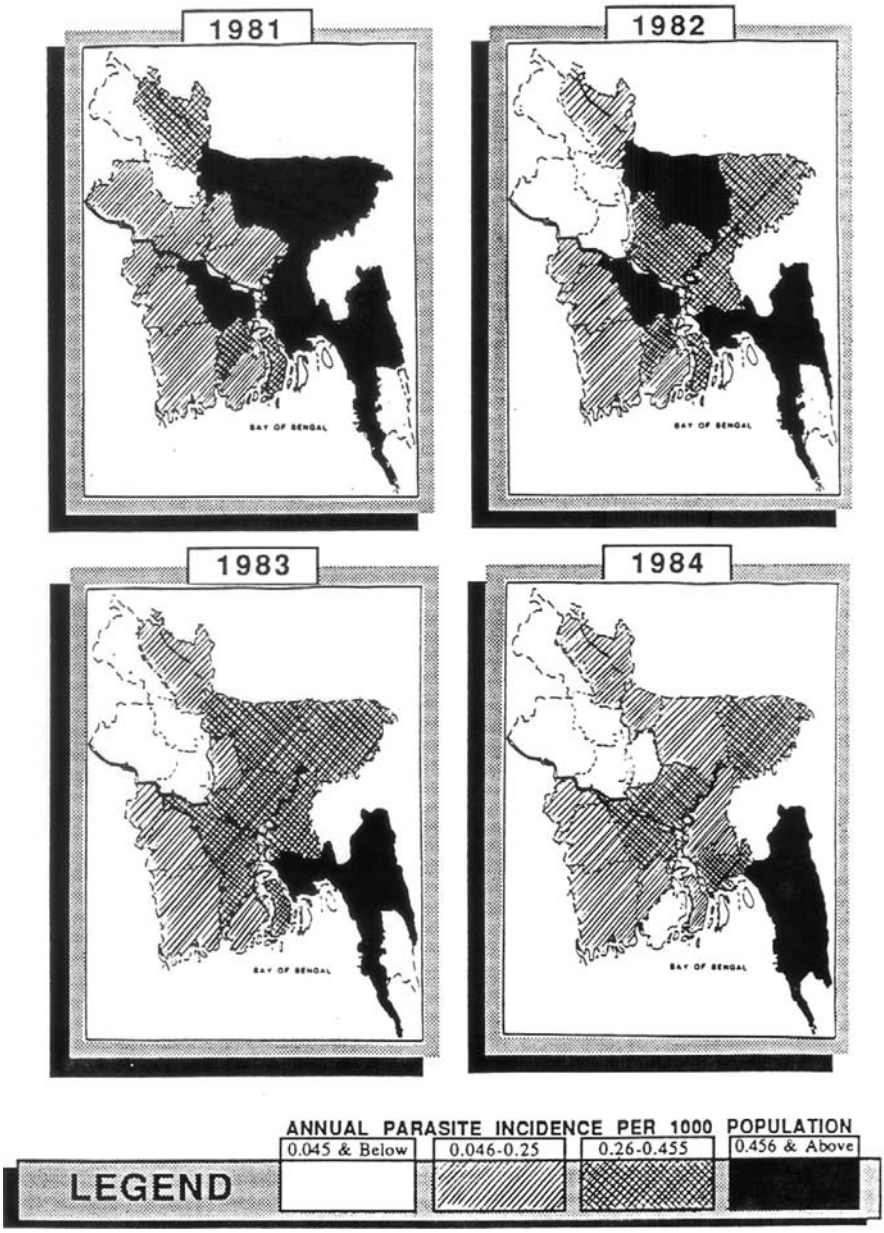


Fig. 5.6 Annual parasite incidence per 1,000 population for Bangladesh, 1981–1984
Source: Prepared by authors based on data from Statistical Yearbook of Bangladesh 1991 and 1993, Dhaka: Bangladesh Bureau of Statistics.

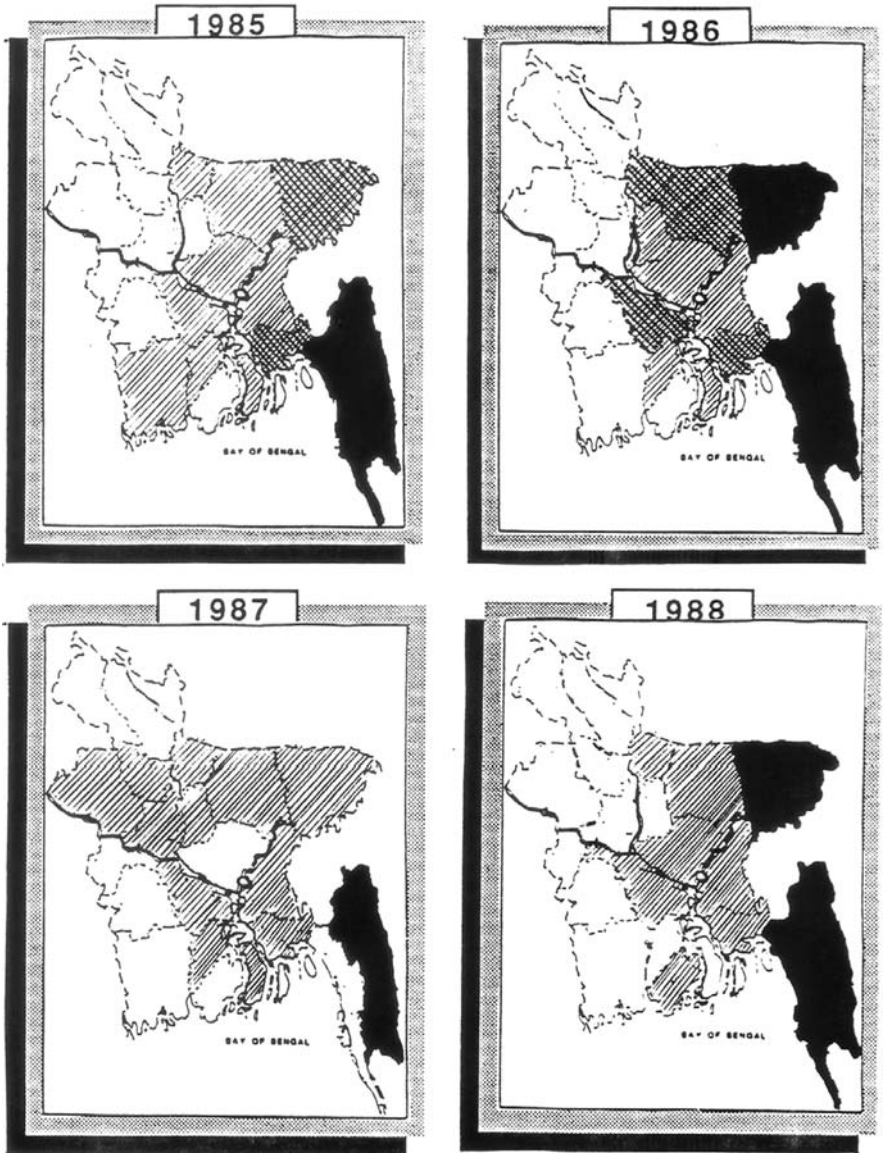


Fig. 5.7 Annual parasite incidence per 1,000 population for Bangladesh, 1985–1988
Source: Prepared by authors based on data from Statistical Yearbook of Bangladesh 1991 and 1993, Dhaka: Bangladesh Bureau of Statistics. Legend as that of Fig. 5.6.

malarial were in the forested areas. As in India, the next phase of the post-resurgence period in Bangladesh possibly heralds the spread of the disease, both in previously hyperendemic areas and in epidemic areas. Thus, Paul's (1984) rationale remains true of the resurgence period in parts of Bangladesh.

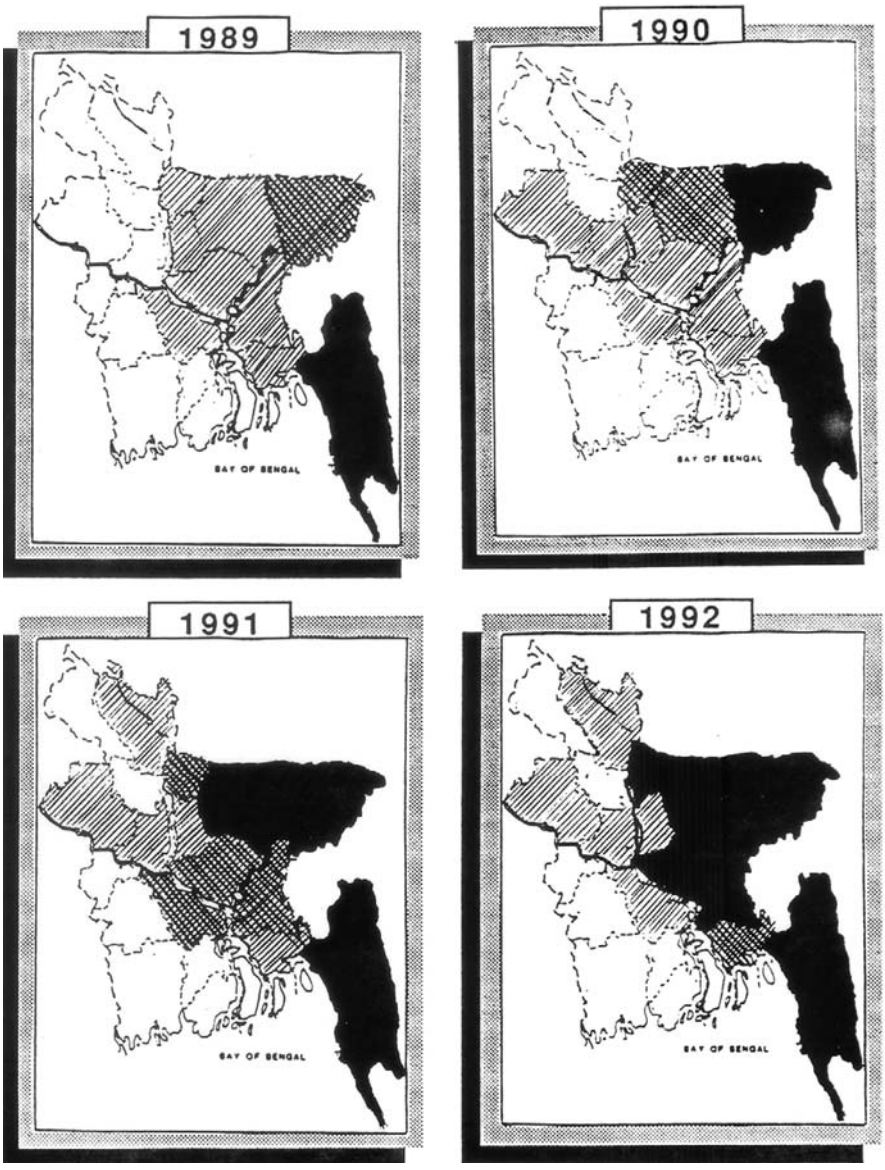


Fig. 5.8 Annual parasite incidence per 1,000 population for Bangladesh, 1989–1992
Source: Prepared by authors based on data from Statistical Yearbook of Bangladesh 1991 and 1993, Dhaka: Bangladesh Bureau of Statistics. Legend as that of Fig. 5.6.

Vectors and Malarial Ecology in Bangladesh

It is evident from the studies of Dutta and Dutt (1978) that all of Bangladesh has an ecologically conducive environment for malarial occurrence. Their study also concludes that the southern deltaic fringe of Bangladesh, Chittagong, Chittagong Hill Tracts, and Banderban areas are most conducive to malarial occurrence year-round, whereas the rest of Bangladesh remains endemic with seasonal high occurrences from August to December (Dutta and Dutt 1978).

It is the female *Anopheles* mosquito that is the malarial vector. Of the 31 different *anophelines* in Bangladesh, only four vectors cause malaria in humans. They are *A. philippinensis*, *A. sundaicus*, *A. minimus*, and *A balabacensis*. Boyd (1948) mapped the distribution pattern of various vectors and mentioned only the first three to be the major ones. According to Boyd (1948), *A. philippinensis* "Ludlow 1902" was the most widespread vector. *A. sundaicus* "Rodenwalat 1925" was found in the brackish water of the southern fringe of the delta (the active part), which is largely covered with the dense Sunderban forest. Sandosham and Thomas (1983) found that in Malaysia, this vector has been found in houses, has a preference for human blood, is a powerful flier, breeds most favorably in stagnant water exposed to sun light, is found on the limit of tidal rise, and can breed in organically polluted water. The southern fringe of the Bangladesh delta falls in Spate's (1954) category of "active delta with little stagnant water" and in the zone of very little malaria in Bentley's 1916 map. Paul (1984) found that the Patuakhali district of this zone had a high incidence of malaria in 1968–1971. Since 1984, this entire zone including Patuakhali has shown less than the national average of malaria incidence. *A. sundaicus* has never been a serious malaria threat in Bangladesh (Boyd, 1948) and the incidence pattern of the disease since is a fair indication of its not being a serious threat in the near future.

Boyd's (1948) map showed that *A. minimus* was the main vector only in the hills of North, Northeast, and East Bangladesh. However, Kondrashin and Rashid (1987) pointed out the following in a more recent study than the former:

> *A. minimus* was mostly captured from hilly and foothill areas of the central and western districts. The species is highly anthropophilic with rates [of human host preference] ranging up to 93%. It rests mainly in human dwellings. This vector species also disappeared during the eradication program but has recently been recorded in very low densities. The maximum prevalence is during the drier months. Its distribution overlaps with *A. balabacensis*, especially in forested foothills (Kondrashin and Rashid 1987, p. 6).

A. minimus "Theobatd 1901" breeds in "small pools at the grassy edges of streams, springs and irrigation channels in clear water" (Sandosham and Thomas 1983, p. 194). It has not been a serious threat as a malaria vector in recent times.

A. balabacensis or *dirus* "Peyton and Harrison 1979" has been identified as the most effective malaria transmitter of the hilly areas of eastern and northeastern Bangladesh, an area confirmed by this study to be under significant threat of malaria. This vector, found in the Philippines, Kalimantan in Indonesia, Thailand, Laos, Cambodia, Vietnam, Malaysia, Myanmar and Northeast India, caused havoc in Bangladesh as well. It is not known whether it was present in Bangladesh

earlier, because it has been identified only in the later part of the twentieth century. It might have migrated recently from Myanmar and propagated in Bangladesh in large numbers. This species has a great avidity for human blood. It also multiplies very fast because "the number of eggs laid by this species varied from 65 to 162" (Sandosham and Thomas 1983, p. 191).

> *A. balabacensis* (now *A. dirus*) is the notorious malaria vector of Bangladesh. It breeds and rests in forests. It was first incriminated as a vector in Chittagong Hill Tracts in 1967. Later, in 1970 and 1971, it was found sporozoite positive in Sylhet district. It feeds throughout the night both indoors and outdoors but maximum biting activity takes place around midnight (Kondrashin and Rashid 1987, p. 6).

Resurgence and Post-resurgence Periods

Resurgence of malaria in Bangladesh started in 1972 and continued to have an upswing of incidence until 1976–1977. A waning period followed, with a low dip in 1987 that heralded another stage: the post-resurgence period. In the following section the spatial characteristics of both periods have been assessed.

The malaria database for district-wise analysis has been gathered from the *Statistical Yearbook of Bangladesh 1991 and 1993* published by the Bangladesh Bureau of Statistics (BBS 1991; BBS 1993). The population data have been obtained from 1981 and 1991 national censuses, while intervening years' populations have been estimated from graphical extrapolations. For the purposes of this study, the authors standardized the data by using the measure of API.

A 12-year API analysis starting from 1981 shows some significant spatial patterns in Bangladesh (Figs. 5.6, 5.7, and 5.8). First, Chittagong, Chittagong Hill Tracts, and Banderban have remained the areas with highest API rates almost throughout the 12-year period. Second, the northwest was the area of least incidence during this period. Third, a declining trend of spatial incidence continued from 1981 ending in 1987. The year 1987 was the end of the resurgence cycle, with a sharp reduction in morbidity; the decline occurred primarily because of the malaria control efforts. Fourth, there is a similarity in patterns of malaria incidence of 1981 and of 1992, except that the southeastern areas including the active and moribund delta were virtually malaria-free in 1992. In fact, declining incidence of malaria in the southwest started from the year 1987. Fifth, malaria incidence in the Dhaka district was high for the first time in 1992, which had particularly alarming consequences because this district not only has a large population and the highest population density, but also the best linkages with the rest of the country, which in turn can expedite diffusion of disease. Sixth, during the resurgence and post-resurgence periods, malaria seems to have been diffusing from the forested areas of east and northeast Bangladesh, and hilly areas of northeastern India, where the vectors were left unchallenged and the infected individuals remained unattended even during the malaria eradication phase.

Another method for the district-wise comparative assessment of the decline or increase in malaria incidence during the 12-year period is by standardizing dates

of occurrence by indexing. Assuming an index value of 100 for the 1981 API rate, bar graphs have been drawn for subsequent years for 19 districts (Figs. 5.9, 5.10, 5.11, and 5.12). Some revealing facts have been observed from the bar graphs. First, certain districts such as Barisal, Khulna, Kushtia, and Jessore all situated in the southeast had shown an increase of API rates through 1982 and 1983, but by 1992 the rates witnessed a significant decline, reaching negligible levels of 0.02, 0.01, 0.01, and 0.01, respectively (Figs. 5.9A B, C, D). All these districts fall in

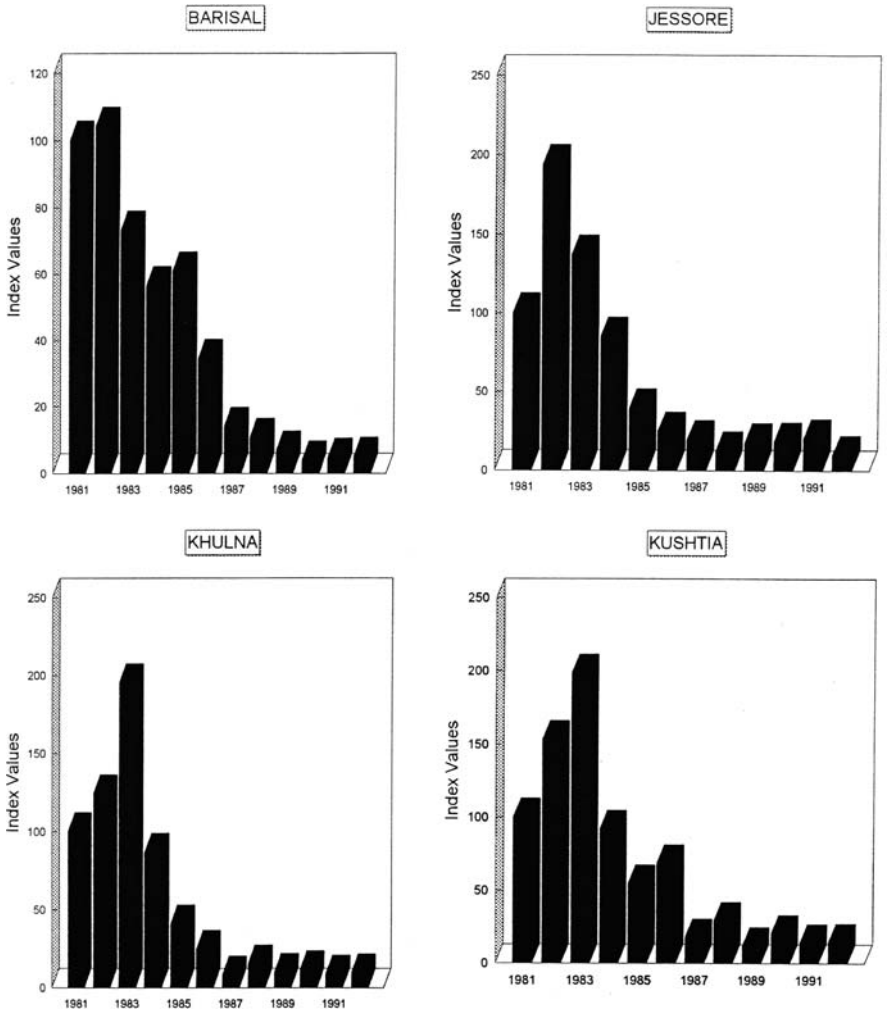


Fig. 5.9 District-wise index values of malarial incidence for Bangladesh, 1981–1992
Note: 1981 = 100 index value. (Districts: Barisal, Jessore, Khulna, and Kushtia).
Source: Calculated by authors based on data from Statistical Yearbook of Bangladesh 1991 and 1993, Dhaka: Bangladesh Bureau of Statistics.

the delta area where malaria control measures and larval elimination programs are widespread and particularly effective on *A. philippinensi*s.

Second, there are several districts that have a convex growth pattern with low incidence in 1987–1988, when the resurgence period ended with rates of hitherto lowest national incidence. These districts are Dhaka, Faridpur, Chittagong, Chittagong Hill Tracts (Fig. 5.10), Rangpur (Fig. 5.11), Comilla, Dinajpur, Noakhali, and Rajshahi (Fig. 5.12).

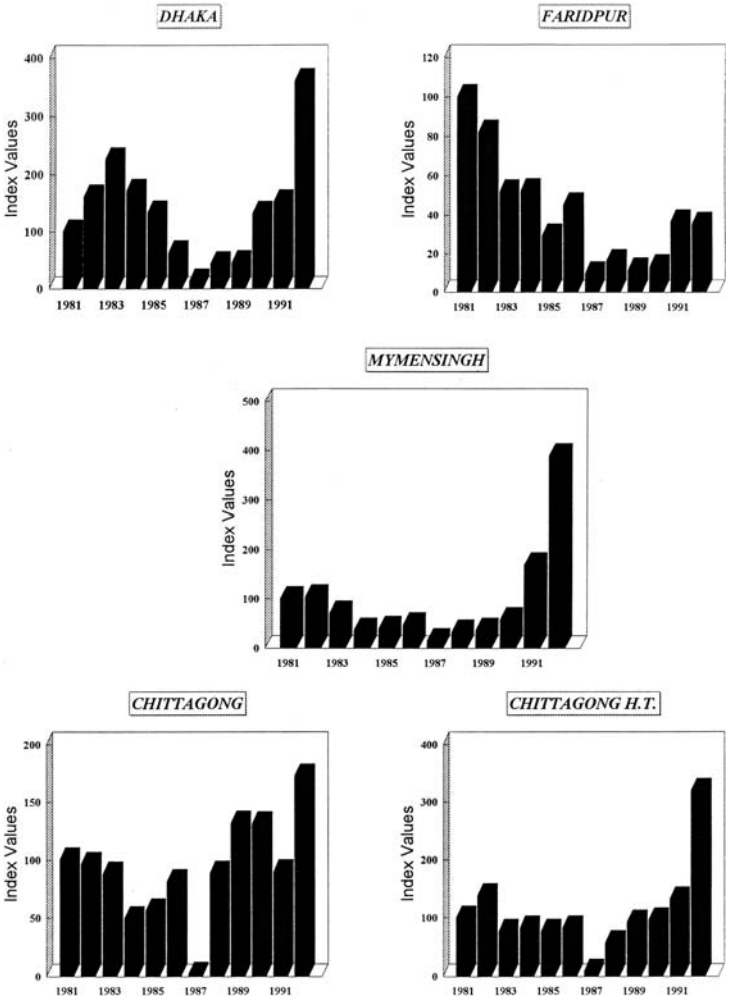


Fig. 5.10 District-wise index values of malarial incidence for Bangladesh, 1981–1992
Note: 1981 = 100 Index Value. (Districts: Dhaka, Faridpur, Mymensingh, Chittagong, and Chittagong Hill Tracts).
Source: Calculated by authors based on data from Statistical Yearbook of Bangladesh 1991 and 1993, Dhaka: Bangladesh Bureau of Statistics.

Third, there are certain districts with more than one peak of API indices in the 12-year period; for example, Dhaka, Rangpur, Jamalpur, Pabna, Bogra, Sylhet, and Tangail (Fig. 5.11). Fourth, the three southeastern districts of Chittagong, Chittagong Hill Tracts, and Bandarbans had high API rates in 1981, which increased considerably by 1992. Fifth, in the 12-year period, the highest rate of increase took place in Mymensingh (Fig. 5.10), and by 1992 this district had API rates similar to the other high API rate districts of the eastern part of the country.

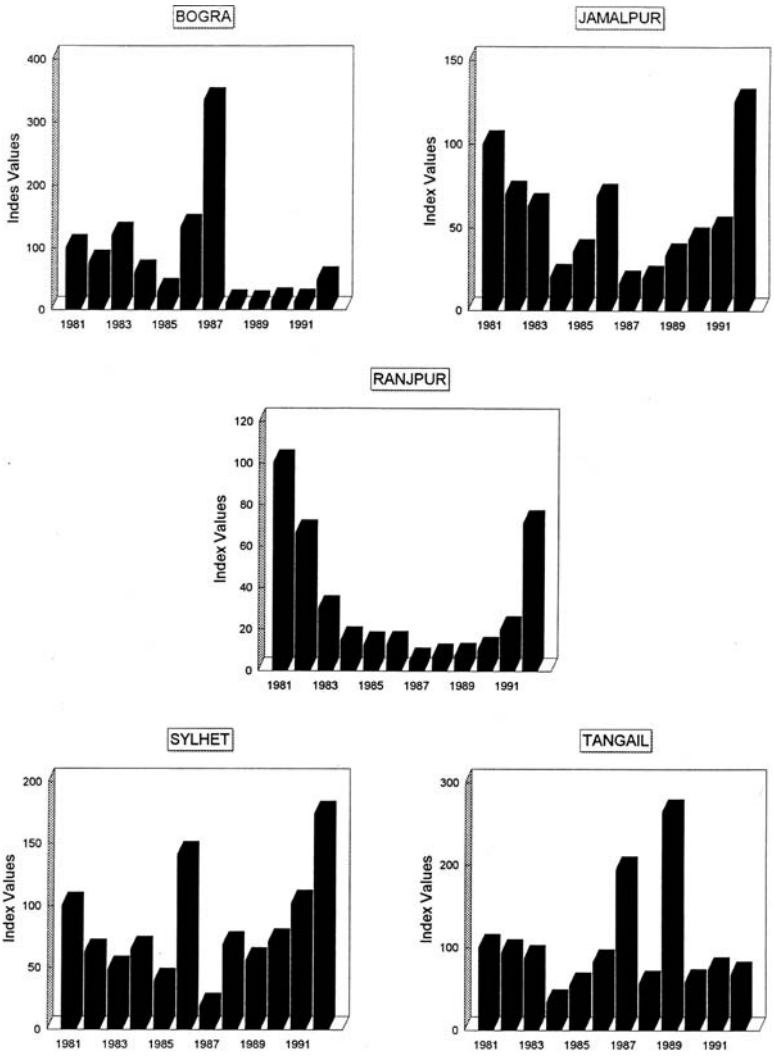


Fig. 5.11 District-wise index values of malarial incidence for Bangladesh, 1981–1992
Note: 1981 = 100 Index Value. (Districts: Bogra, Jamalpur, Rangpur, Sylhet, and Tangail).
Source: Calculated by authors based on data from Statistical Yearbook of Bangladesh 1991 and 1993, Dhaka: Bangladesh Bureau of Statistics.

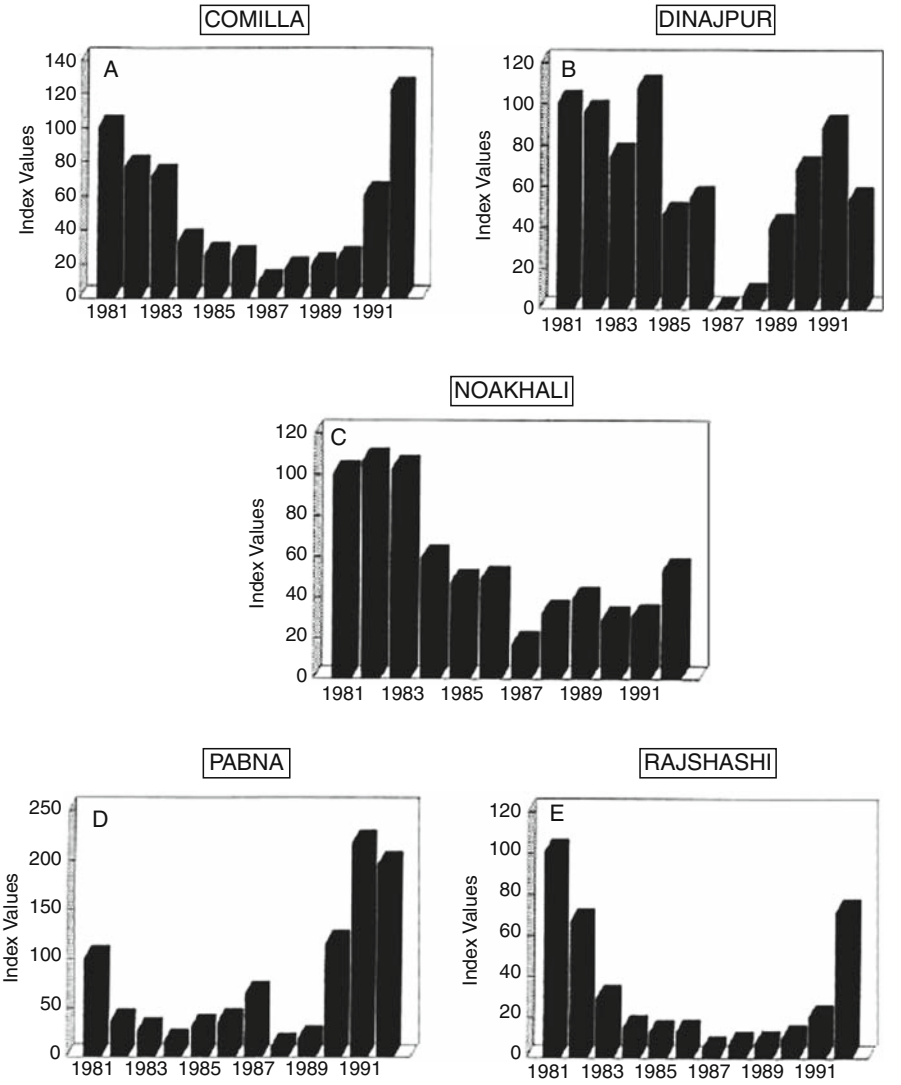


Fig. 5.12 District-wise index values of malarial incidence for Bangladesh, 1981–1992
Note: 1981 = 100 Index Value. (Districts: Comilla, Dinajpur, Naokhali, Pabna, and Rajshashi).
Source: Calculated by authors based on data from Statistical Yearbook of Bangladesh 1991 and 1993, Dhaka: Bangladesh Bureau of Statistics.

Eradication: Challenges and Innovations

The belief that malaria was eradicated in the mid-1960s in India and in the early 1970s in Bangladesh proved to be untrue because total elimination had not been possible, and malaria spread widely in those two countries from the remaining affected pockets. Moreover, in continents like Africa, where more than a million deaths occurred every year and malaria morbidity was several more times that number (WHO 1999), the disease was never considered "eradicated." The fact remains that in the poor, tropical, and semi-tropical countries with suitable ecology for endemic malaria (Dutta and Dutt 1978), farmers and people in general have no alternative but to remain exposed to mosquito bites. Window and door screens are affordable in the developed countries, while many of the poor in the developing countries cannot even afford to have mosquito nets while they sleep. Access to and affordability of doctors are more possible in the developed countries while such possibilities become slimmer in the developing countries. Thus, when an individual contracts malaria in a developing country, he/she is likely to be a greater factor in spreading the disease than an infected person in an affluent country. There are also other reasons that retard efforts in malaria eradication. One such reason is effectively summed up by Hudson (1995, 46), ". . .mosquitoes throughout the tropics have become immune to DDT used to control them, and [the parasite to] the drug chloroquine, used to treat people already infected."

Given the present economic conditions, the only way malaria can be eliminated in Bangladesh is by the introduction of a vaccine or through the promising science of genetic engineering. However, as the introductory chapter explains, scientists have had only limited success with malaria vaccines as yet, mostly resulting in questionable efficacy. However, with new combination drugs and vector-control techniques in use, malaria can possibly be controlled to a great degree. Until this commitment to combat malaria in a concerted manner is made, it will remain a potent disease in developing countries with warm climates, and its severe impact will merely be retarded in countries like Bangladesh.

Conclusion

Bangladesh is one of the countries in the developing world that simply cannot finance its anti-malaria activities on its own. Yet, the control of malaria is not only humane but also very necessary for its agricultural prosperity, because a farmer debilitated with malaria is an inefficient cultivator. Therefore, the continuation of malaria control activities by the WHO and others in the international community is extremely necessary.

Historically, malaria has gone through different cycles of upswing and downswing. Since 1987 it has taken an upswing, which has been designated as the post-resurgence period, unfolding different epidemiological challenges. First, in the last few years of the century, malaria was diffusing from the east, in contrast to the colonial times when the disease usually diffused from the west to the east (Fig. 5.13).

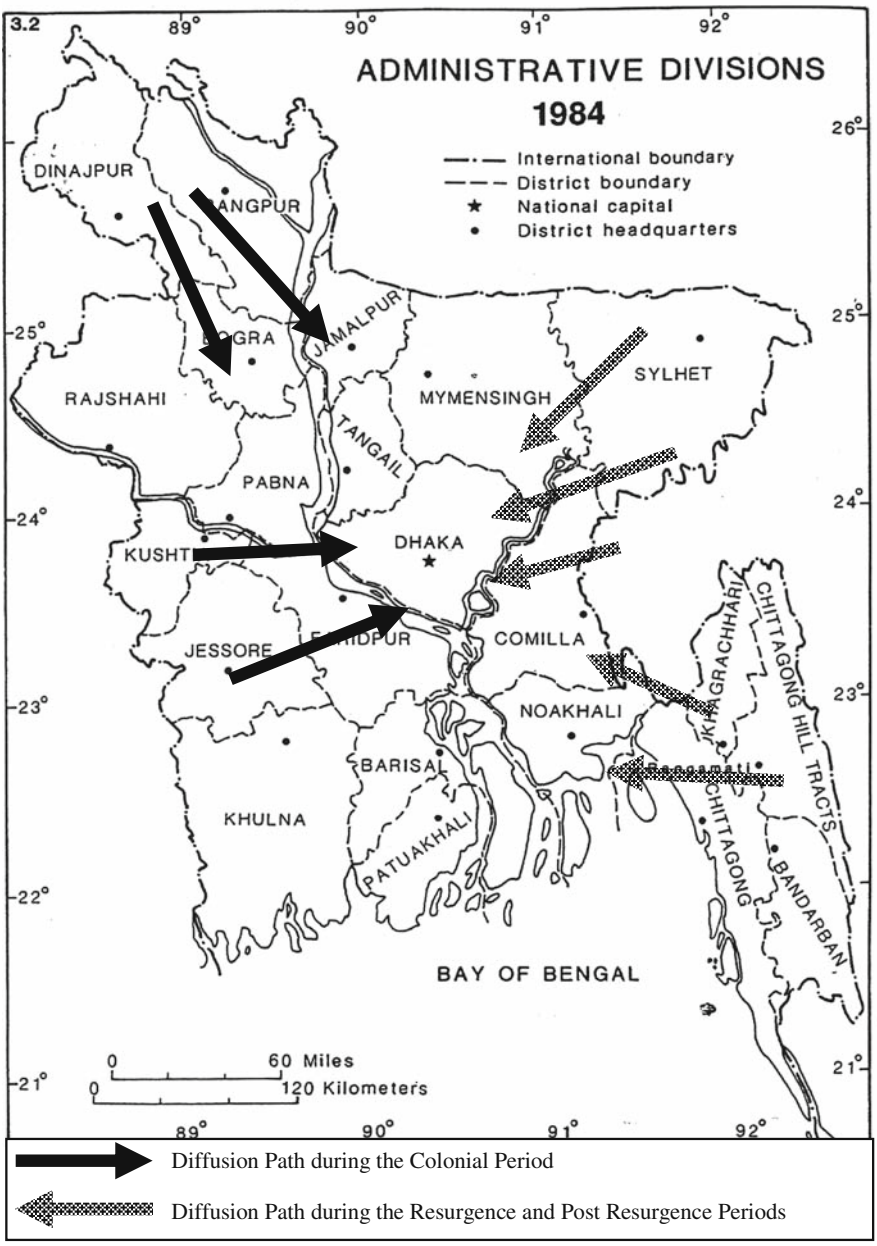


Fig. 5.13 Diffusion path of malaria in Bangladesh
Source: Prepared by Dutt.

Because the original eastern disease reservoir is the forested area of both Bangladesh and India, eradication entails a collaborative international effort and also combating malaria in the forested and rainy environments, which are the habitat of the notorious vector, *A. balabacensis (dirus)*. It is quite possible that in spite of large-scale spraying of Malathion (which has replaced DDT in this region) for destruction of larvae and the use of anti-malaria drugs, malaria is here to stay in the country.

When a significant positive economic change occurs, malaria is likely to be eradicated in the same manner that it was in Singapore. Such a seachange in Bangladesh's economic situation is not likely in the immediate future. Under these circumstances, a pragmatic strategy of controlling the disease in high incidence target population groups along with general control measures elsewhere is desirable. Given the lack of human and economic resources and the malaria-conducive environment, total eradication through preventive measures alone seems unfeasible. The situation will not change as drastically as it did in the case of smallpox unless a malaria vaccine is discovered or an effective genetic engineering technique is identified.

Note

1. Annual parasite incidence or annual parasite index is calculated by dividing positive blood samples in an area by population of the area in thousands.

References

Boyd, M.F. 1948. *Malariology*. Philadelphia: Saunders.

Dutt, A.K. and M. Gieb. 1996. *Fully Annotated Atlas of South Asia*. New Delhi: Oxford and IBH, p. 154.

Dutta, H.M. and A.K. Dutt. 1978. Malarial Ecology: A Global Perspective. *Soc Sci Med.* vol. 12: pp. 69–84.

Griffin, C.C. 1992. *Health Care in Asia: A Comparative Study of Low Cost Financing*. Washington, DC: The World Bank.

Harrison, G. 1978. *Mosquito, Malaria and Man: A History of Hostilities Since 1880*. New York: E.P. Dutton.

Hudson, L. 1995. First Malaria Vaccine Trial Results Prove Disappointing in Gambia. *India Abroad*. September 15: p. 46.

Kondrashin, A.V. and K.M. Rashid (eds.). 1987. *Epidemiological Considerations for Planning Malaria Control in South-East Asia Region*. New Delhi: WHO, SEARO.

Learmonth, A.T.A. 1957. Some contrasts in the regional geography of malaria in India and Pakistan. *Trans. Inst. British Geog*. vol. 23: 37–57.

Paul, K.B. 1984. Malaria in Bangladesh. *Geographical Review.* vol. 74, January: pp. 63–75.

Sandosham, A.A. and V. Thomas. 1983. *Malariology with Special Reference to Malaya*. Singapore: Singapore University Press.

Schwartzberg, J.E. (ed.). 1992. *A Historical Atlas of South Asia*. New York: Oxford University Press.

Spate, O.H.K. 1954. *India and Pakistan: A General and Regional Geography*, London: Methuen & Co., Ltd.

Spate, O.H.K. and A.T.A. Learmonth 1967. (3rd edn.). *India and Pakistan: A General and Regional Geography*. Bungay, Suffolk, GB: Methuen & Co. Ltd.

Statistical Yearbook of Bangladesh, 1991. Bangladesh: Bangladesh Bureau of Statistics.
Statistical Yearbook of Bangladesh, 1993. Bangladesh: Bangladesh Bureau of Statistics.
WHO 1999. *The World Health Report 1999: Making a Difference*, Geneva.
World Bank 1995. *World Tables*. Baltimore, MD: The Johns Hopkins University Press and World Bank.

Chapter 6
Resurgence of Malaria in Bangladesh

K. Maudood Elahi and Sabiha Sultana

Abstract This chapter discusses malaria incidence in a general background of mortality and morbidity in Bangladesh. Specifically, it aims to look into (a) the conditions associated with the resurgence of malaria and its status by the close of the twentieth century; (b) the spatial trend of malaria resurgence in the same time period, additionally suggesting the division of the country into three risk zones based on epidemiological, geo-ecological, and infrastructural criteria; and (c) the possibility of research intervention in the field of malaria geography.

Keywords Mortality · Morbidity · Bangladesh

Mortality and Morbidity: A General Background

Bangladesh, along with her geographical neighbors, has long been witness to most of the major causes of death common in preindustrial societies and those endemic in tropical/subtropical regions. Epidemics and famines have been common. Effective community health care and medical facilities date back only a few decades. As such, the general level of health has been very low. Until well into the first half of the twentieth century, there was fairly high mortality and morbidity, with slow growth of population despite high fertility.

The high levels of mortality persisted until 1931, when it dropped slightly, but then continued to be on the high side until 1941. Thereafter, the crude death rate showed a gradual decline, although it was affected by the Great Famine of 1943, but then returned to its earlier trend within a decade. For the next decade or so the mortality rate in Bangladesh registered further decline, reaching 19 deaths per thousand in 1961. It registered an increase in 1971, but then began to decline in the subsequent

K.M. Elahi (✉)
Department of Environmental Science and Pro-Vice Chancellor of Stamford University Bangladesh, Dhaka, Bangladesh
e-mail: elahikm@stamforduniversity.edu.bd

R. Akhtar et al. (eds.), *Malaria in South Asia*, Advances in Asian Human-Environmental Research 1, DOI 10.1007/978-90-481-3358-1_6,

Table 6.1 Crude death rates: Bangladesh, 1881–1991

Year	CDR per 1,000
1881	41.0
1891	44.0
1901	46.0
1911	47.0
1921	42.0
1931	38.0
1941	41.0
1951	30.0
1961	19.0
1971	34.9
1981	19.0
1991	11.2

Sources: Davis 1951; BBS 1995

decades (Table 6.1). In 1970–1971, the death rate showed an upward trend due to higher mortality resulting from the cyclone of 1970 (which cost 0.5 million lives) and the War of Liberation of 1971 (registering deaths at 3.3 million). It is assumed that the mortality rate has gradually returned to the predisaster level to follow the normal trend (Table 6.1) (Bangladesh Bureau of Statistics (BBS) 1995; Davis 1951).

Mortality and Malaria: Dynamics of Change

The declining trend in the death rate that started before World War II reasserted itself in the early 1950s. The level of mortality fell by nearly 50% in the period 1951–1961. This was primarily a result of health-care measures taken in the earlier decades, but more particularly due to the measures undertaken during this period to control a number of communicable diseases endemic to this area (Elahi 1977). Malaria has long been an important cause of death, but all forms of dysentery, diarrheas, and gastroenteric diseases (including typhoid) were also important causes of mortality (Elahi and Ruzicka 1981).

As noted earlier, the recent decline in mortality was the consequence of measures undertaken to check the intensity of epidemics and local diseases combined with improvement in maternity and health conditions. It is also equally true that the country's population explosion was caused by falling mortality which itself was a function of the process of modernization in general. Modernization brought improved shelter, more food (especially by expanding agricultural technologies), better education, better transportation, and improved sanitation around and after the mid-twentieth century. It has probably contributed more to the decline in mortality than have specific health measures (Elahi and Ruzicka 1981). As a result, malaria occurrence became negligible, and the targets in the attack and preparatory phases of the malaria eradication program were achieved by 1965 (Government of Pakistan (GOP) 1966). This achievement was reflected in the change in national mortality

Table 6.2 Estimated proportion of death from malaria in Bangladesh, 1901–1994

Year	Percentage of total deaths
1901–1911	72.30*
1950–1960	15.00
1976	0.07
1988	0.09
1989	0.27
1990	0.18
1991	0.63
1992	2.00
1993	2.50
1994	4.64

*Probably included typhoid, small pox, and fever associated with other causes.
Sources: Elahi and Ruzicka 1981; and calculated from Directorate of Health (DOH) 1995.

rates caused by malaria (Table 6.2). Subsequently, by 1970 the program of malaria eradication was thought to have been near completion.

Brief Survey of Literature

Since levels of health and disease vary over space and time, there is ample scope to develop an understanding of the importance of relationships between the geographic aspects of these issues, which are the prime subject matter of medical geography. Literature on medical geography is quite prolific, as given in Akhtar and Verhasselt (1990). In South Asia, India has contributed significantly toward this understanding of relationships under the purview of medical geography (Dutt and Jaiswal 1985). A pioneering study by Learmonth (1958) was an important contribution to research on environment and health linkages incorporated into the incidence of malaria in the South Asian subcontinent. Subsequently, the specific works of Akhtar and Learmonth (1985), Dutt et al. (1980), and Dutta et al. (1979) on malaria resurgence in India led to the rethinking of spatial aspects of the endemicity of the disease. Meanwhile, Fonaroff (1991) offered new dimensions on research in medical geographic approaches to malaria that are of high methodological value. Moreover, Dutta and Dutt (1978) studied malarial ecology with a global perspective and provided specific references on South Asia.

Despite the significant role of malaria in the mortality and morbidity situation as well as in the endemic milieu of diseases in Bangladesh, research on medical ecology and any recent expansion of the knowledge base by social scientists has been virtually nonexistent in the case of Bangladesh. The existing literature is mostly medical/clinical in nature, with the exception of two studies by Elahi (1977), and Elahi and Ruzicka (1981) and one by Paul (1984) shed light on malaria as it affects the mortality situation of the country.

Methodology

This study is based purely on secondary sources of data on malaria surveillance. The Directorate of Health (DOH), Government of Bangladesh has systematically collected such data at the district level since 1990. Additionally, temporal data at national level have been available since 1963. For the present purpose, an overall pattern of resurgence of malaria for the country has been captured for the 1963–1994 time span. In order to understand the nature of spatial characteristics and variation of malaria incidence, a series of trend surface maps based on relevant variables have been prepared for 1991, 1992, 1993, and 1994. These portray the pattern and the propensity of malaria resurgence in the country.

The specific geographic conditions of areas vulnerable to malaria have been discussed using field reports obtained through news media during 1994–1995. Efforts have been made to correlate malaria ecology with the local and regional geographic environment, using characteristics of hydrology, landform, and climate. These measures have not been quantified. This leaves open options for using better analytical tools for explanation, such as the application of GIS techniques for the preparation of composite maps using multiple variables associated with malaria ecology in the country.

Malaria in Bangladesh

Historically, malaria has been relatively less severe in Bangladesh in comparison to many parts of South Asia because of very thorough flushing of almost every water body by the convergent river system, and the sheet floods from local rains. Some areas of exception have been those where rivers were less numerous, such as Rangpur, Chittagong Hill tracts, and the moribund delta in southwestern Bangladesh (Bengal) (Learmonth 1958). Until 1951, at least 15,000 people died annually from malaria in Bangladesh (Cockburn 1960).

As observed by Learmonth (1958), most areas now forming Bangladesh had formerly been known as healthy plains (where spleen rate was less than 10%) due to thorough flushing from yearly floods and flowing rivers. Malaria incidence was more frequent in the peripheral districts with hilly terrain and relatively few riverine tracts or dying rivers, and mortality due to malaria was quite high in these areas. Even in inland areas, malarial fever cases had been numerous due to several conditions other than ecology.

Much of the *Anopheles* breeding grounds were formed by the practice of draining a paddy field to adjacent fallow land or nearby lower ground or *khals.* Burrow pits dug alongside numerous roads, railways, *bandhs* (embankments) in the country have always been the potential sources of *Anopheles* breeding. In fact, it has been almost commonplace knowledge that malaria is not merely a mosquito-borne disease, but is a part of a vicious cycle along with poverty, malnutrition, ignorance, overpopulation, and illiteracy (Elahi 1981).

However, as noted earlier, the incidence of malaria had mostly been controlled by the mid-1960s through the malaria eradication program in collaboration with

the WHO (Table 6.2). During the decade 1950–1960, spraying of long-lasting insecticides, mainly DDT, in human settlements to eliminate the mosquito vector, surveillance to detect new cases through periodic checking of blood for the causative parasite, and treatment with effective anti-malarial drugs had been the major elements of this program. As a result, the death rate from this cause was also reduced to negligible levels.

In 1961, a time limited malaria eradication program was launched in the country, which progressively covered the whole country, except the northern and eastern parts. But malaria reappeared in some parts of the country, thought to be the result of relaxation of surveillance in the period following the achievement of near-zero malaria mortality, as well as existence of stagnant water bodies along the expanding transport network, flood control embankments, and the many neighboring settlements offering breeding grounds for mosquitoes. In 1977, the malaria eradication program was converted to the malaria control program, its main emphasis being vector control in areas identified as susceptible to malaria occurrences and intensities. In the time since, malaria has only become a larger problem than before, affecting the productive age-group (15+ years) disproportionately since 46% of total malaria cases occur in this age-group. the proportion of *P. falciparum* cases to the total also increased over the years, particularly since 1999, reaching an alarming rate of 78.5% in 2005. Additionally, gross under-reporting of malaria and shortcomings in surveillance are common, and epidemic response to the yearly focal outbreaks is usually weak (WHO/SEARO n.d). This has created a worrisome situation simulating the problems of the resurgence years and needs to be tackled with due speed.

Malaria Agents and Vectors in Bangladesh

Malaria is a febrile illness, thus fever is one of the cardinal signs of malaria. All fever may not be malaria, but all malaria except asymptomatic malaria is characterized by fever. Therefore, in an endemic area all fever cases are potential malaria suspects. Differential diagnosis must take malaria as the first consideration. Malaria can only be confirmed by the detection of the malaria parasite—the unicellular *Plasmodium* in the red blood corpuscles (RBC) of blood by microscopic examination (DOH 1988).

Malaria has long been endemic in certain parts of the region now forming Bangladesh. Approximately 10% of the population lives in a high-risk area. In Bangladesh, most malaria cases are attributable to *Plasmodium vivax* and *P. falciparum,* the latter occurring mostly in the high-risk area constituting about 90% of the infection. Other malaria *plasmodia* (e.g., *P. malariae*) are not found in Bangladesh in very high concentrations. *P. falciparum* poses a major public health problem in Bangladesh because of its drug resistant strain. It occurs in the hilly and forested districts of Sylhet, Sunamganj, Bandarban, Rangamati, and Khagrachari, where it is transmitted by the vector *Anopheles dirus* (DOH 1988). The endemicity of malaria in this region is one of the main obstacles to socioeconomic progress in the Chittagong and Cox's Bazar regions, and in the three hill districts of Chittagong, which have potential for agriculture, forestry, farming, hydroelectricity, fisheries,

and tourism. As part of the national development plan, a large number of people were settled in the three hill districts of Bandarban, Rangamati, and Khagrachari. This movement of settlers to malarious areas greatly increased the number of people at risk.

In terms of the malaria vector, in Bangladesh, the recorded number of *Anopheles* is 34, of which four species have so far been incriminated as principal malaria vectors (Fig. 6.1). These are *A. dirus*, *A. philippinensis*, *A. minimus,* and *A. sundaicus.* Among the main factors determining whether a particular species of *Anopheles* is an important vector, the frequency of its feeding on humans is of particular relevance. The other factors are the mean longevity of the local population and of the *Anopheles* species, and its density in relation to humans. Thus, a particular species of *Anopheles* may be an important vector in one area of the world and of no importance in another (DOH 1988). The ecology of mosquito-carrying malaria vectors in Bangladesh is discussed below in brief.

A. dirus balabacensis

A. dirus is the most notorious malaria vector in Bangladesh. It has been recorded in the hilly and forest areas of Jamalpur, Sherpur, Netrokona, Mymensingh, Sylhet, Habiganj, Sunamganj, Moulvibazar, Chittagong and Cox's Bazar, Khagrachari, Bandarban, and Rangamati (Fig. 6.1). This mosquito is found during the monsoon period, usually breeding in small rainwater collections, such as hoof prints, wheel tracks, ditches, and gullies in forests. It is exophagic in nature (feeding outdoors)—resting in mud holes and cavities in the jungle during daytime, but entering houses for a brief period to feed and returning to the jungle after feeding. It has been found to feed mainly at midnight (DOH 1988). The species has been found both infected and infective on several occasions in all the hilly districts and foothill areas of north, northeastern, and southeastern Bangladesh.

A. philippinensis

This species plays a major role in malaria transmission in the vast plains of Bangladesh, except along the narrow coastal belt along the Bay of Bengal (Fig. 6.1). The seasonal prevalence has been observed to be high during the pre-and post-monsoon periods. Their favorite breeding places are tanks, ponds, ditches, rice fields, abandoned marshy channels, burrow pits, dead riverbeds with stagnant water, and marshes (*bils* and *haors*) with submerged vegetation and exposure to sunlight. This species is mostly endophagic (feeding indoors) but after indoor DDT applications, it has become increasingly exophagic in nature.

Both the infected and the infective population of this species have been recorded in many districts of Bangladesh. The species is still considered to be responsible in maintaining the low level of transmission and occasional outbreaks in the vast plain areas of Bangladesh (DOH 1988).

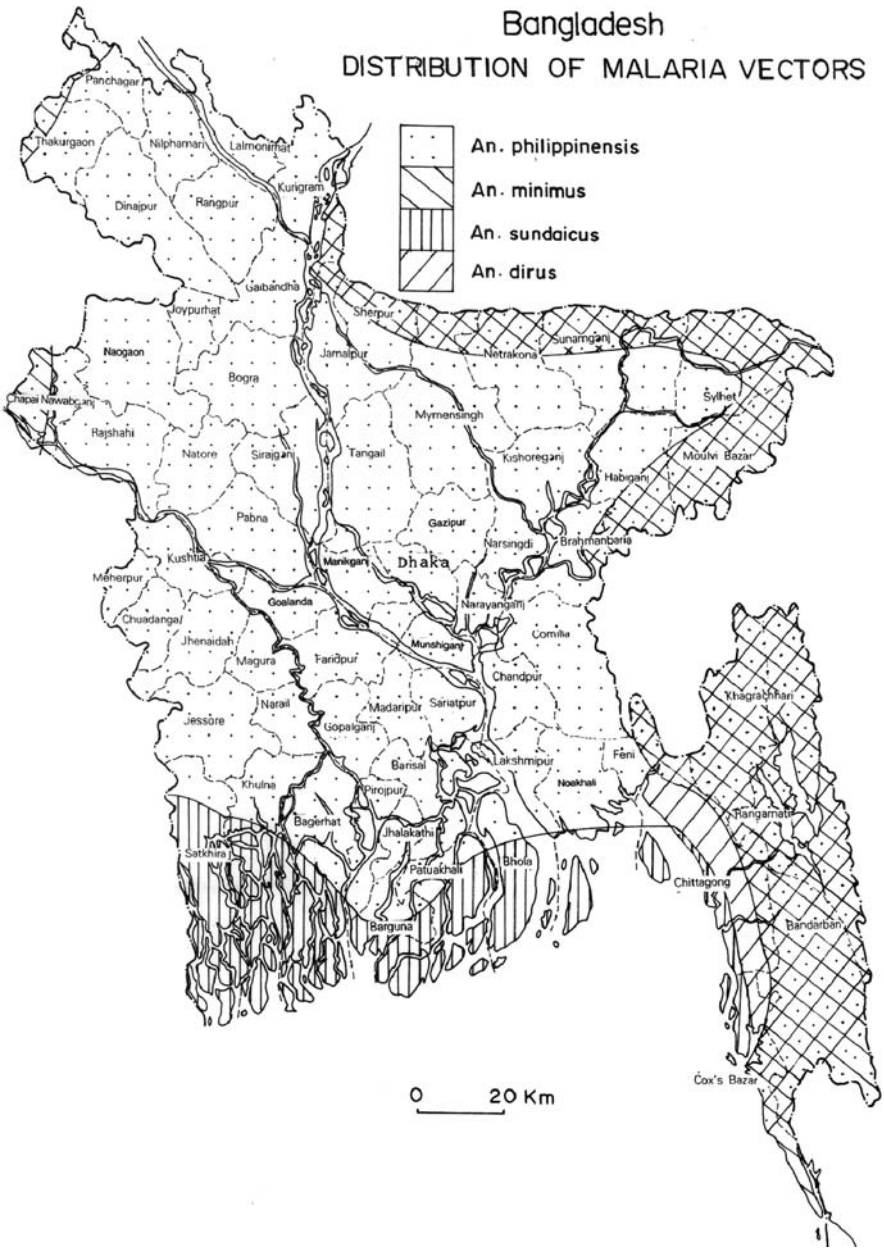


Fig. 6.1 Distribution of malaria vectors in Bangladesh
Source: DOH 1988.

A. minimus

A. minimus has been recorded in hilly and foothill areas of Tetulia, Mymensingh, Tangail (Madhupur), Netrokona, Habiganj, Moulvibazar, Sylhet, Sunamganj, Chittagong, Cox's Bazar, Rangamati, Bandarban, and Khagrachari. The seasonal prevalence of this species has been observed in the post-monsoon period. After DDT application the species tends to disappear, but reappears after a short time, as has happened in Khagrachari, Rangamati, Bandarban, Cox's Bazar, Chittagong, Habiganj, Moulvibazar, and Sylhet. It breeds in flowing water in hilly streams, springs, irrigation ditches, irrigated rice fields, and burrow pits. It is highly endophagic and mostly prefers lower portions of the indoor walls. Its observed biting habit is usually a short while before midnight, with a peak in biting after midnight (DOH 1988). Both infected and infective mosquitoes of this species have been recorded on many occasions in different parts of Bangladesh.

A. sundaicus

This species has been recorded in coastal belts of Khulna, Bagerhat, Satkhira, Pirojpur, Bhola, Barisal, Barguna, Patuakhali, Noakhali, Chittagong and Cox's Bazar (Fig. 6.1). It prefers to breed in enclosed salt or brackish water as found in tanks, pools, marshes, burrow pits, and even in shrimp farms that have been on the increase in many coastal areas. This species is highly endophagic and rests on both human and animal shelters, and biting habits have been recorded throughout the night, although mostly during the first half. Very little research has been done to determine the infection and infectivity rate of this species. However, an estimated 2 to 65% of the infection is caused by this species (DOH 1988).

Resurgence of Malaria

As mentioned, in 1977, the malaria eradication program was changed to the malaria control program under which regular surveillance and control measures have been undertaken. The program mainly concentrates in the southeastern and northeastern districts in Bangladesh, namely, Bandarban, Rangamati, Khagrachari, Cox's Bazar, Sylhet, Sunamganj, Moulvibazar, Netrokona, and Mymensingh. During 1980–1990, the proportion of *P. falciparum* to the human population had increased (Table 6.3). In the hill districts of Chittagong, Cox's Bazar, and tea plantation areas in the north-east, this vector accounts for about 80–90% of the infection. Localized epidemics have occurred in 1986 in areas along the Bangladesh–India border in Sunamganj, Sherpur, and Sylhet (DOH 1995).

The Health Directorate indicated 485 deaths from malaria during the first 5 months of 1995 (DOH 1995). However, of the above, 305 were suspected malaria cases. Of the total, 191 died in Sunamganj, 102 in Sylhet, and 192 in Bandarban, Khagrachari, Rangamati, Cox's Bazar, Mymensingh, Jamalpur,

Table 6.3 Malaria surveillance data of Bangladesh, 1963–1994

Years	Pf%	SPR%	SFR%
1963	22.14	0.47	1.10
1965	13.10	0.07	0.01
1970	49.65	0.11	0.05
1975	62.44	1.07	0.67
1980	32.76	2.57	0.84
1985	52.51	1.10	0.57
1990	63.22	2.20	1.39
1991	47.63	3.05	1.40
1992	44.76	6.03	2.70
1993	43.64	7.67	3.36
1994	48.64	10.02	4.88

PF: *Plasmodium falciparum* infections (including mixed, *falciparum–vivax* infections); SPR: Slide positivity rate (positive cases per 100 slides examined); SFR: Slide *falciparum* rate (Pf infections per 100 slides examined)
Source: DOH 1995

and Netrokona put together. Except Mymensingh and Jamalpur, the rest are designated as malaria endemic zones. An estimated 60,000 persons were affected by *P. vivax*, but cases of *P. falciparum* are not uncommon in the hilly areas (Ahmad 1995).

There were about 50,000 malaria patients in 200 villages of 26 unions under 10 *thanas* or *upazilas*[1] of Sylhet and Sunamganj in the mid-1990s. In Sylhet, malaria had been spreading in Companyganj, Jaintapur, Kanaighat *upazilas*, and parts of Sadar *upazila*. There were about 96 deaths during the first part of 1995 (DOH 1995). This led to the formation of 13 medical teams to work in these *upazilas*. In Sunamganj, the affected areas are Tahirpur, Doarabazar, Biswamharpur, Dharmapasha, Chhatak, and Sadar *upazilas*. Most of the affected areas lie in the *haor* area where the communication system is very poor. Treatment of malaria is hindered because terrain conditions restrict movement of medical personnel, health workers, and medical supplies (Siddiquee 1995). This greatly hampers the effective treatment of malaria. Field reports suggest that Indian authorities began spraying Malathion in the areas of Amlang, Lengthal, and Khasia Basti adjoining the Bangladesh border to check the outbreak of malaria. This might have led to the flight of malaria-carrying mosquitoes into Bangladesh, affecting its bordering *upazilas* in Sylhet and Sunamganj (Siddiquee 1995).

Further west, in Sherpur, malaria also broke out in a vast area bordering India, affecting over 5,000 people. The worst affected *thanas* were Sherpur, Jhenaigati, Nalitabari, Sribordi, Bakshiganj, and Dewanganj (Daily Star 1995a). Despite the efforts of the government to control the infection through spraying of DDT, fresh batches of mosquitoes carrying the malaria vector from forest and marsh areas across the border moved into Bangladesh, aggravating the situation.

In Khagrachari, Rangamati, and Bandarban districts, both *P. vivax* and *P. falciparum* strains are common, causing a higher death rate from malaria. For instance, during June–July of 1995, malaria claimed 27 lives in Ramgarh (Khagrachari). Eight out of 10 *upazilas* of Rangamati, i.e., Rajasthali, Barkal, Jurachhari, Baghaichhari, Langdu, Naniarchar, Kaukhali, and Belaichhari were severely affected (Daily Star 1995b). A second area of this part of Bangladesh affected by malarial fever was the Cox's Bazar district. Worst affected *upazilas* were Teknaf, Ukhia, Ramu, Chakaria, and Cox's Bazar itself. About 500 deaths were recorded in the 12-month period, and over 32,000 persons were identified as affected. It is believed that this sudden outbreak of malaria diffused from adjoining bordering areas of Arakan in Myanmar through the influx of the agent-carrying mosquitoes from the forest and low-lying areas of northwestern Myanmar, and through the movement of Rohingya refugees from the Arakan region. It is in this area that *P. falciparum* caused numerous cases of cerebral malaria, which causes death within 24 h (Khan 1995).

Apart from the above regions of highly endemic malaria, malaria is also prevalent in several pockets within the rest of Bangladesh. These are Narayanganj and Chapai Nawabganj. However, neither of these areas have yet been categorized as epidemic in nature.

The temporal pattern of resurgence of malaria since 1963 is shown in Table 6.3. There is a strong relationship between slide positivity rate (SPR or malaria positive cases per 100 slides examined) and slide *falciparum* rate (SFR or *P. falciparum* (Pf) infections per 100 slides examined)—the value of r being 0.877. The trend surface maps of the district-wide surveillance data on the proportions of Pf and SPR for 1991–1994 are shown in Figs. 6.2a–d and 6.3a–d. A trend of spatial spread of malaria incidence is evident from the northeast and southeast areas to the interior and west of the country, and the incidence of malaria has also been on the increase over these years.

Malaria Zones

On the bases of vector and parasite prevalence and malaria infection rates (Figs. 6.1, 6.2, and 6.3, respectively), Bangladesh may be divided into a number of strata with respect to malaria endemicity and level of susceptibility, which themselves are based on three criteria:

(a) epidemiological—considering malaria parasites and vectors
(b) geo-ecological—considering surface hydrology and local climate
(c) infrastructural—interventions of development affecting the above two

Using these criteria, Bangladesh may be divided into High, Medium, and Low malaria risk zones.

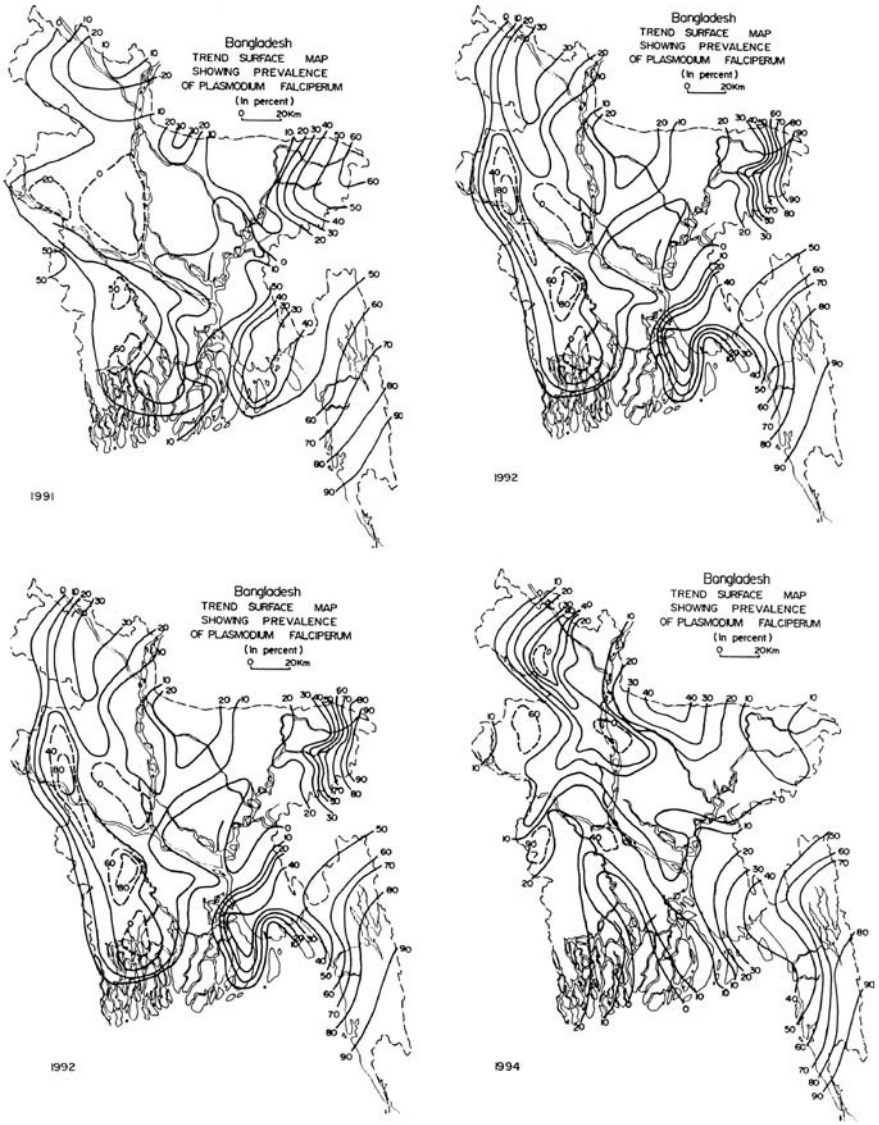


Fig. 6.2 Trend surface map showing prevalence of *Plasmodium falciparum* in Bangladesh, 1991–1994
Source: DOH.

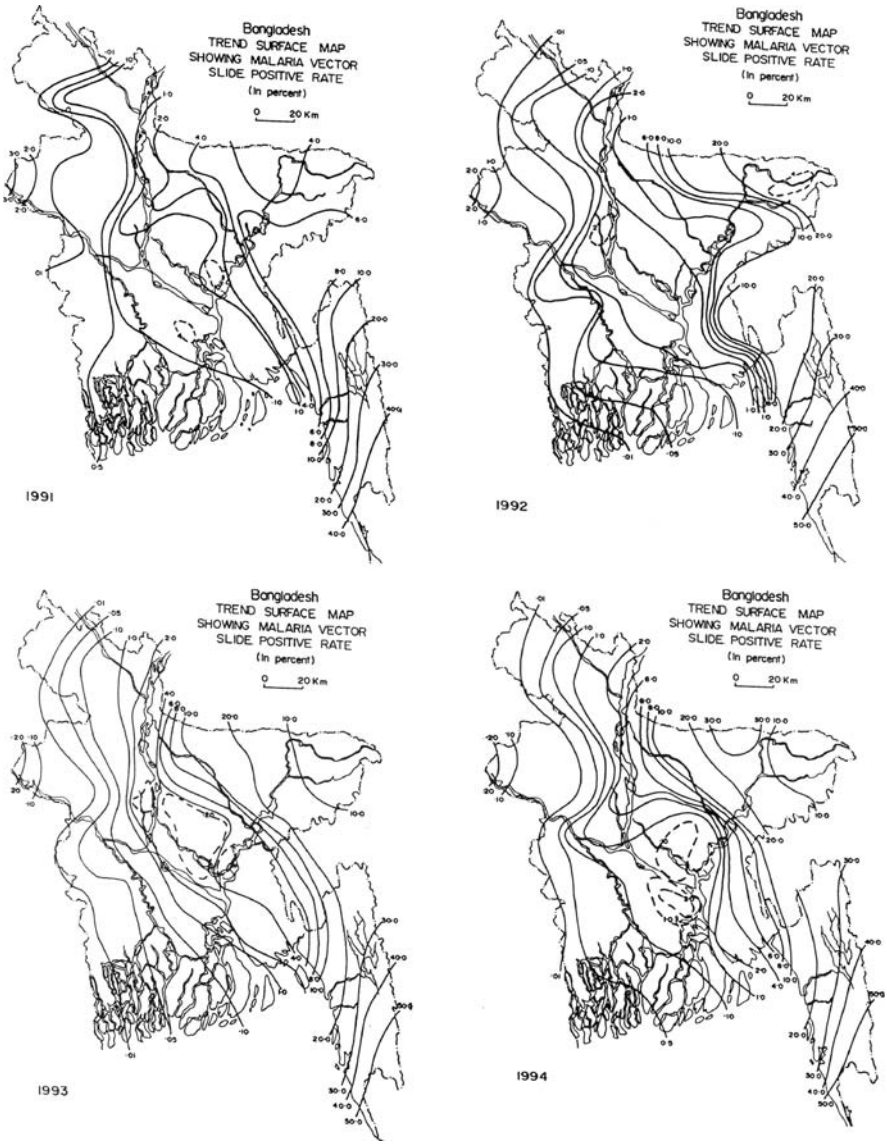


Fig. 6.3 Trend surface map showing malaria vector slide positivity rate in Bangladesh, 1991–1994
Source: DOH.

High Malaria Risk Zone

This zone covers the border districts with India in the northeast, and with India and Myanmar in eastern and southeastern Bangladesh. The zone is characterized by low hills with tropical forests, and areas where forest cover is cleared by

plantation agriculture and traditional rice culture. It is also a very high rainfall area with an intricate river network and enclosed water bodies and marshes. The expanding transport network often tends to obstruct the natural flow of water and irrigated rice fields with high cropping intensities allow the collection of extensive stagnant water in farmlands. These offer ideal breeding grounds for mosquitoes. In this zone *P. falciparum* is the dominant species of *plasmodia*, with pockets of insecticide resistant *A. dirus* and/or *A. minimus* mosquitoes (DOH 1988). This zone covers about 10% of the total population of the country.

Medium Malaria Risk Zone

This zone lies adjacent to the first, having similar rainfall conditions, but varied surface hydrological conditions. In Narayanganj, existence of stagnant water from abandoned/dry riverbeds offers breeding ground for malaria-carrying mosquitoes. Towards the west, there has been a significant change in local surface hydrology in this area and in the adjoining areas in India due to the construction of the Farakka Barrage over the Ganges River in India, and other flood control and irrigation projects. This area is also affected by malaria vectors from across the Indian border. In the whole region, irrigation canals developed for agriculture, burrow pits along roads, and embankments also provide habitats for mosquitoes. The growing shrimp culture in the coastal regions of Khulna, Bagerhat, Satkhira, Cox's Bazar, and a few other areas also offer ideal breeding grounds for mosquitoes in the enclosed water bodies of the shrimp farms and the burrow pits dug alongside. There are a significant number of *P. falciparum* cases, where the main vectors are *A. philippinensis* and *A. sundaicus.* This zone covers about 12% of the population (DOH 1988).

Low Malaria Risk Zone

A major part of Bangladesh included in this zone is characterized by a vast flood plain that has undergone changes in surface hydrology and rainfall conditions in recent decades. In areas with extensive flood control projects (as along the Brahmaputra–Jamuna right bank areas), land reclamation areas (as in the Chalan *bil*, Salanga areas, and G.K. Project areas), extensive burrow pits, and numerous human-made small, enclosed water bodies, excellent breeding grounds for malaria vectors abound. A number of roads built in an unplanned manner in both Khulna and Rajshahi divisions also led to the formation of seasonally stagnant water bodies. An increasing number of shallow stagnant water bodies in dying riverbeds in northern Bangladesh and the Kushtia-Jessore areas also provide breeding grounds for mosquitoes. In this zone, *A. philippinensis* is the active vector, and *P. vivax* is the only indigenous malaria species. It covers 78% of the affected population of the country (DOH 1988).

Conclusions

Anti-malaria operations in Bangladesh still depend largely on vector control with DDT (indoor residual spraying), mainly in the high-risk zone. However, due to the refractory behavior of the vectors in this zone, coupled with operational reasons, DDT spraying had limited impact on the reduction of malaria transmission (DOH 1988).

Consequently, the spatial extent of malaria and its intensity were observed to be on the increase in the later years of the twentieth century. The trend of spatial spread was from the northeast and southeast Bangladesh toward the interior and the west of the country. In view of this, malaria control became a national health issue, and it was felt that the concern should not be limited only to the high-risk zone. It was also felt that the population should be made aware of the possible epidemic form of malaria all over Bangladesh, of the need to use mosquito nets while sleeping and of available anti-malaria drugs. In the high-risk zone, these nets may be treated with mosquito repellents that are not harmful to humans (controversial DDT may be replaced by Delta Methrine and Malathion, which are known to be less hazardous). As science and technology bring greater advancement, more and better preventive and curative methods might also become available, which should also be made available to the public.

There are certain logistic problems hampering malaria control efforts, mostly with respect to manpower, transport, and communication. Inaccessibility of the low-lying areas, hilly terrain, and scattered human settlements in the high-risk zone still pose a formidable problem. This is particularly so during the monsoon and post-monsoon periods, when deployment of paramedics and other medical personnel becomes a major problem. On the other hand, an acute shortage of doctors, the alleged unwillingness of medical personnel to live in remote rural areas, and an often irregular and insufficient supply of insecticides and medicines compound the problem. In most malaria-infected areas the lack of health awareness in general, discontinuance of prophylactic courses of medicines, negligence toward clearing of garbage and stagnant water, and the non-use of mosquito curtains among the population worsen the situation.

Meanwhile, wrong diagnoses and consequent unsuitable treatment are not uncommon amongst the medical personnel. In urban areas, roadside ditches, choked up sewage systems and drains, open latrines, stockpiled garbage along the roads, and congested makeshift shops and houses in slums provide ideal mosquito breeding habitat. These conditions are at their worst in Cox's Bazar, Feni, Narayanganj, Sylhet, and many other smaller towns in the country. The local municipal authorities are in the best position to take necessary action. For this, appropriate logistical supports and a degree of coordination with malaria control efforts are required to be provided to these local authorities.

It should be noted that there have not been enough epidemiological studies incorporating a range of relevant geographical and environmental variables. In fact, apart from surveillance coupled with limited malaria control activities, there is a lack of complete understanding of transmission and ecology of malaria vectors,

and the related impact of regional development activities on human habitat and other biogeographical characteristics. Since malaria eradication is a complex medical, logistic, and administrative undertaking, such an understanding is essential in embarking upon any operational program to combat malaria.

Malaria is not an isolated disease within Bangladesh alone. It is a part of the malaria regime encompassing both South and Southeast Asia. Therefore, the prospect of a regional approach to control and eradicate malaria vectors in this whole Asian region may be regarded as an effective and possible strategy for the constituent countries. An interdisciplinary and interregional approach to the understanding of malaria geography is essential. The untapped skills and advanced techniques of analyses used in the geographic explanation of phenomena can bring about a unified research output for better explanation of epidemiological problems such as the resurgence of malaria in South and Southeast Asia, including Bangladesh. Meanwhile, as concluded in the previous chapter, malaria cannot be eradicated from Bangladesh, but incidence can be lowered to quite an extent with greater emphasis placed on vector control and drug administration, particularly in the high-risk zone.

Note

1. *Thanas* or precincts were the administrative sub-divisions in use at the time of the study. These have now been re-designated as *upazilas* or sub-districts, a term used in this paper from this point on to facilitate ease of understanding for the contemporary reader.

References

Ahmad, K. (1995), Malaria, Diarrhea Claim 1033 Lives so Far, *The Daily Star*, 29 May, Dhaka.

Akhtar, R. and Learmonth, A.T.A. (1985), Resurgence of Malaria in India, 1965–76, in R. Akhtar and A.T.A. Learmonth (eds), *Geographical Aspects of Health and Disease in India* (New Delhi: Concept Publishers), pp. 107–123.

Akhtar, R. and Verhaselt, Y. (eds). (1990), *Disease Ecology and Health: Readings in Medical Geography* (Jaipur: Rawat Publishers).

Bangladesh Bureau of Statistics (BBC) (1995), *Statistical Pocket Yearbook, 1994* (Dhaka: Government of Bangladesh).

Cockburn, T.A. (1960), 'Infectious Diseases and the Population of East Pakistan,' in M.L. Qureshi (ed.), *Population Growth and Economic Development* (Karachi: Pakistan Institute of Development Economics).

DailyStar (1995a), News Report, 24 May. Dhaka.

DailyStar (1995b), News Report, 6 July. Dhaka.

Davis, K. (1951), *The Population of India and Pakistan*. New Jersey: Princeton.

DOH (1995), Malaria Cases Detected in Bangladesh, 1963–94: Data Sheet (unpublished). Dhaka: Directorate of Health, GOB.

DOH (1988), Training Manual on Malaria Control for Medical Officers. Dhaka: Directorate of Health, GOB.

Dutt, A.K. and J.Jaiswal (1985), Two approaches to Medical Geography: A Review, in S.C. Mukhopadhyay (ed.), Geographical Mosaic: Professor K.G. Bagchi Felicitation Volume (Calcutta: Modern Book Agency), pp. 498–511.

Dutt, A.K., R. Akhtar and H.M. Dutta (1980), Malaria in India with Particular Reference to Two West-Central States. Social Science and Medicine, vol. 14d, pp. 317–330.
Dutta, H.M. and A.K. Dutt. (1978), Malarial Ecology: A Global Perspective. Social Science and Medicine, vol. 12, pp. 69–84.
Dutta, H.M., A.K. Dutt, and G.Vishnukumari (1979), The Resurgence of Malaria in Tamil Nadu. Social Science and Medicine, vol. 13d, pp. 193–196.
Elahi, K.M. (1977), Recent Trends in Fertility, Morality and Population Increase in Bangladesh, in L.A. Kosinski and Webb, J.W. (eds), Population and Scale: Macro-populations (Edmonton: IGU Commission on Population Geography).
Elahi, K.M. (1981), Aspects of Medical Geography in Bangladesh, in K.M. Elahi (ed), Perspectives on Bangladesh Geography (Dhaka: BNGA).
Elahi, K.M. and Ruzicka, L.T. (1981), Trends and Differentials in Morality. In ESCAP. Population of Bangladesh (New York: UNO).
Fonaroff, L.S. (1991), Rethinking Malaria Geography: Problems and Potentials for the Profession, in R. Akhtar (ed), Environment and Health (New Delhi: Ashish).
Government of Pakistan (GOP) (1966), Third Five Year Plan (1965–70). Karachi: Planning Commission.
Khan, A.M. (1995), Cerebral Malaria Taking Epidemic Proportion in Cox's Bazar. The Daily Star. 6 August. Dhaka.
Learmonth, A.T.A. (1958), Medical Geography in Indo-Pakistan. The Indian Geographical Journal, vol. 33, no. 1–2, pp. 1–59.
Paul, B. (1984), Malaria in Bangladesh. Geographical Review, vol. 74, no. 1, pp. 63–75.
Siddiquee, I. 1995. Cerebral Malaria Spreading Fast in Sylhet, Sunamganj. *The Daily Star*, 24 May. Dhaka.
WHO/SEARO (n.d.). Malaria situation in SEAR Countries, Bangladesh. Retrieved July 27, 2009 from WHO/SEARO website http://www.searo.who.int/EN/Section10/Section21/Section340_4015/htm

Chapter 7
The Resurgence of Malaria in Pakistan: A Geographical Evaluation

Iqtidar H. Zaidi and Jamil H. Kazmi

Abstract This chapter examines the occurrence of malaria in Pakistan within the framework of "game theory," where the two players are nature and humankind. The degree of malaria resurgence would determine which one of the two players have been more effective. The chapter tracks malaria resurgence by analyzing the malaria situation in 1973 and 1978, the years closest to the highest and lowest points of malaria occurrence following the launch of the malaria eradication program. Using the measures of malaria transmission rate and malaria transmission trend, it was found that malaria intensity was higher in more developed areas where the eradication program provided good coverage. This paradox may be explained by faulty assumptions in program policies, making it likely that even if nature's hand is strong, humankind can hope to contain malaria through better, more effective, and sustained interventions.

Keywords Pakistan · "Game theory" · Malaria intensity · Malaria eradication program

The fact that malaria is a serious, communicable, environment-related disease has become well established in medical science and medical geography literature. The disease has been called by different names such as "jungle fever," "swamp fever," and "ague," all of which are classed as intermittent fever. The term "malaria" is itself made up of two Italian words: "mal" (bad) and "aria" (air). In Italy and other parts of Europe, "intermittent fever" was reported to have been common among people living near wetlands, swamps, and newly plowed lands. The landscape contained a great deal of dampness, with decaying organic materials in the air. It was thought the infection was caused by coming in contact with "bad air," "swamp air," or "marsh gas," an assumption emphasizing that the fever resulted from miasmas being emitted from moist ground (Frenkel and Western 1988; Pinder 1973).

J.H. Kazmi (✉)
Department of Geography, University of Karachi, Pakistan
e-mail: jkazmi@usa.net

Note: Dr. Zaidi passed away in 1999

R. Akhtar et al. (eds.), *Malaria in South Asia*, Advances in Asian Human-Environmental Research 1, DOI 10.1007/978-90-481-3358-1_7,

As mentioned in Chapter 1, at the turn of the nineteenth century, Ronald Ross, a British officer and physician in the Indian Medical Service, demonstrated that the malaria organism was introduced into the blood by the bite of the *Anopheles* mosquito. Thus, the theory that the mosquito was actually responsible for transmitting malaria shifted the emphasis from the environment in general, to preventive methods aimed at mosquito elimination, protection from bites and prophylaxis.

It was in the context of the above understanding that the malaria eradication program (MEP) was undertaken in Pakistan in 1961. Launched with a view to eradicating malaria from Pakistan by the year 1974, the program was conducted under the guidance of and with financial assistance provided by WHO and USAID. In the early years, the program progressed well. By 1966, malaria incidence was brought down to the lowest ever rate of 0.19% slide positivity rate (SPR),[1] and it was from this trough level that malaria resurged.

This chapter deals with spatial patterns of the above-mentioned malaria resurgence in Pakistan during the later half of the twentieth century. Resurgence of malaria implies its reappearance from a low, inconspicuous, generally non-threatening position to a conspicuously hazardous one. The low is generally brought about by human interruption in the process of malaria transmission, such as through the initiation of the MEP in the case of Pakistan. In retrospect, it seems that there were lapses on the part of the program managers due to which the 1966 low could not be further reduced or even maintained. The resurgence of malaria in Pakistan became so serious that by the mid-1980s, approximately 19% of the total mortality in the nation was reported to be caused by malaria (Federal Bureau of Statistics, Government of Pakistan [GOP] 1986).

The analysis of the intensity of malaria resurgence presented here intends to provide an understanding of areal variations in the operational effectiveness of the MEP. This type of performance assessment of the MEP attempts to offer a more realistic basis for justifying the validity or non-validity of the underlying idea that malaria can be eradicated. This can help the MEP managers to devise more efficient strategies to satisfactorily interrupt malaria transmission. There exists a general dearth of such studies in Pakistan, therefore, this study is expected to create a better awareness of the status of malaria in Pakistan in the later half of the twentieth century and of how geographical approaches can be meaningful in future medical research and health-care planning.

The Conceptual Framework

The resurgence of malaria and the MEP's managers' reaction to it can be compared to a game between two players, nature and humankind. On one side, nature causes malaria transmission, and on the other, humankind (through the MEP) generates intervention strategies to outwit nature. Thus, a conceptual framework such as game theory can be employed to point out weaknesses in MEP's management strategies that led to malaria resurgence. As Peter Gould has observed, this theory provides "an imposing structure dealing, in essence, with the question of making rational

decisions in the face of uncertain conditions by choosing certain strategies to outwit an opponent, or, at the very least, to maintain a position superior to others" (Gould, 1963, 290). It is within the framework of this theory that an attempt has been made to explain malaria resurgence in terms of its inverse relationship with the effectiveness of MEP.

The data used in the study were derived mainly from the relevant *Annual Reports of the Director of General Health* (GOP). Some of these reports provide detailed information at several different spatial scales or zones, labeled malaria control zones (MCZs) (see Fig. 7.1). By the late 1990s, there are 42 MCZs that were specifically created for the purpose of carrying out the malaria eradication program. In the north-west frontier province (NWFP), Punjab, and Sindh, most of the MCZs coincide with the districts. These MCZs are further subdivided into sectors and subsectors.

The present study is based on data collected for 37 MCZs for which data were available, pertaining to the years 1973–1974 and 1978. These years have been selected because they complete the cycle of malaria resurgence that started in

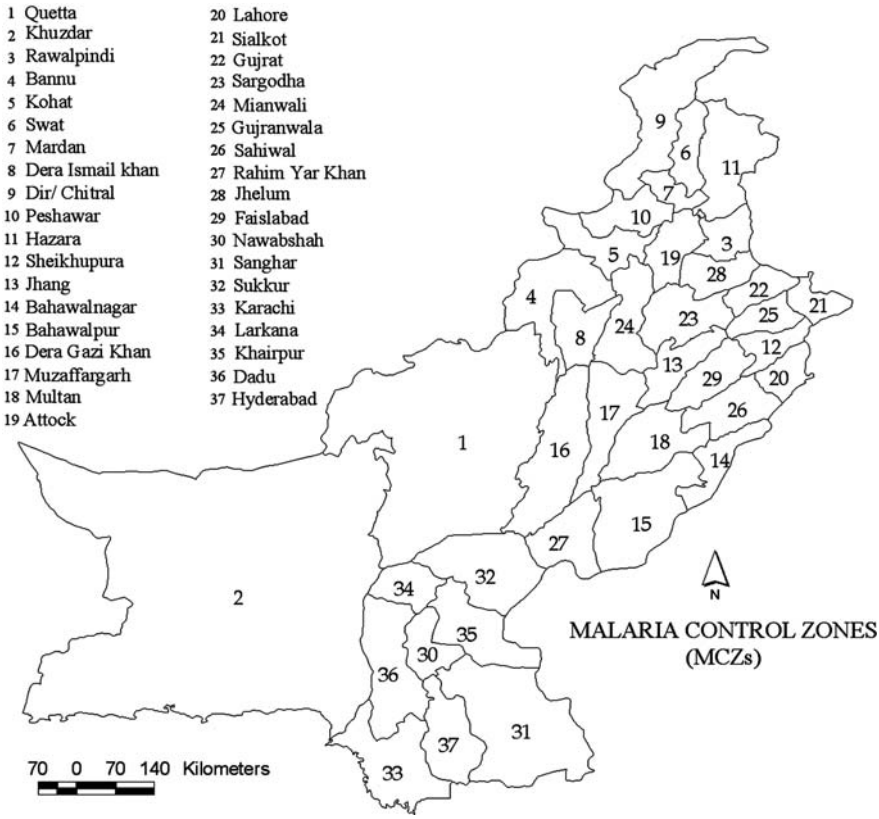


Fig. 7.1 Thirty-seven malaria control zones of Pakistan
Source: Based on annual reports of the director general of health, GOP.

1972–1973, which presumably intensified the activities of the MEP. Malaria cases were brought down to a minimum in 1979, for which the detailed data were not available. Hence, the year 1978 was selected as the data point closest to 1979, and as a reference point for ascertaining the epidemiological position at that time. This period may be taken as completing a round of the game between humankind and nature. For the purpose of this study, malaria incidence was measured in terms of SPR.

An Overview of Malaria Resurgence in Pakistan

As can be gathered from the *First, Second, and Third Five Year Plans* of Pakistan (National Planning Board, Government of Pakistan (GOP) 1955; National Planning Commission, GOP 1960; 1965) and the *Annual Reports of the Director of Federal Health* (GOP 1975; 1978; 1979; 1980; 1984a), the planners in Pakistan continued to perceive malaria as the most serious communicable disease in Pakistan, but thought it could be controlled and eventually eradicated through relatively low-cost direct control techniques such as public health measures, mainly involving the systematic spraying of DDT.

Malaria's high morbidity and mortality rates adversely affect all human activities. Since it is a disease closely associated with the development of irrigation systems in Pakistan, it mainly affects the agricultural community, particularly during the sowing and harvesting seasons. In view of this image of malaria, planners recommended that a nationwide malaria eradication program be launched during the First Five Year Plan Period (1955–1960) at an estimated cost of Rupees 23 million (just under USD 5 million as calculated by using 1960s exchange rates[2] and USD 285,360 as per June 1, 2009 exchange rates). In response to this recommendation, the Government of Pakistan joined the MEP in 1961, after a Presidential Ordinance of 1960 that launched a 14-year plan to eradicate malaria from Pakistan, spanning 1961–1974. Technical and financial assistance was provided by WHO and USAID. Since malaria was regarded primarily as a rural problem, urban areas were excluded from the MEP. The exclusion of urban areas from MEP was a great blunder by the planners. As a result, malaria gained considerable ground in the cities of Pakistan in early 1970s.

The MEP progressed satisfactorily up until 1966, when the SPR fell to a low of 0.19%. Thereafter, the malaria situation began to worsen rapidly. By 1972 and 1973 the SPR rose to a peak of 14.58%and 14.09%, respectively. During these years, approximately 650,000 microscopically confirmed cases of malaria were reported, even though the actual malaria cases were estimated to be more than 10 million. Vector resistance against insecticides, exclusion of urban malaria from the control program, poor participation of general health services, false economic drives, and prevailing socioeconomic conditions were thought to be responsible for this resurgence (GOP 1980).

The epidemiological position of malaria in Pakistan as a whole, as revealed by SPRs from the base year 1960–1983, has been waxing and waning (Table 7.1).

Table 7.1 Epidemiological position of malaria in Pakistan, 1960–1983

Year	Slide positivity rate in percent (SPR)	Year	Slide positivity rate in percent (SPR)
1960	15.57	1972	14.58
1961	3.15	1973	14.09
1962	0.92	1974	9.82
1963	2.17	1975	7.43
1964	1.49	1976	4.27
1965	0.79	1977	1.78
1966	0.19	1978	0.62
1967	0.25	1979	0.45
1968	0.35	1980	0.59
1969	0.98	1981	1.25
1970	2.80	1982	1.70
1971	5.36	1983	1.70

Source: GOP 1984a.

These fluctuations are thought to be associated with the occurrence of rainfall and floods. After the 1972–73 peak, the SPR gradually fell to a low of 0.45% in 1979, then began to rise again. Overall, measured in terms of SPR, the magnitude of malaria incidence and population affected by the disease was very high in Pakistan and its various provinces (Table 7.1). According to the *National Health Survey 1982–1983*, in terms of incidence, malaria ranked number one among all the diseases at national and provincial levels (GOP 1986). In fact, the incidence of malaria in Pakistan was recorded to be more than three times higher than the next two highest ranking diseases (Table 7.2).

As stated in Chapter 1, epidemiologically, malaria is a three-factor disease: agent (parasite), host (human), and vector (mosquito) (May, 1950). *Plasmodium falciparum* (*Pf*) and *Plasmodium vivax* (*Pv*) are the most common parasites in Pakistan (Table 7.3). For example, in 1976, *Pf* was responsible for 30.0% of the total positive slides indicating malaria infection, whereas *Pv* was responsible for 69.7% of the infections in Pakistan as a whole (GOP 1978) (Table 7.3). However, using trend data from 1978 to 1987 in the province of Sindh as an illustrative example,[3] we can

Table 7.2 Position of malaria among five top-ranking diseases by provinces of Pakistan, 1982–1983

	Pakistan		Baluchistan		N.W.F.P.		Punjab		Sindh	
Diseases	% SP	R	% SP	R	% SP	R	% SP	R	% SP	R
Malaria	40.4	1	35.1	1	26.6	1	42.3	1	43.8	1
Common cold	6.5	2	3.3	7	9.7	2	6.8	2	5.2	3
Respiratory diseases	5.1	3	6.2	3	5.7	4	4.6	3	6.8	2
Stomach diseases	4.2	4	5.0	4	4.5	5	3.7	6	3.4	6
Infectious diseases	3.5	5	9.6	2	7.9	3	2.7	7	3.0	8

SP = Sick Persons, R = Rank.
Source: GOP 1986.

Table 7.3 Percent distribution of malaria cases showing infection of various kinds of parasites

Provinces	Pf	Pv	Mixed	Total positive slides
Punjab	31.1	68.7	0.2	105,806
Sindh	47.5	51.5	1.0	6,194
N.W.F.P.	6.7	92.8	0.5	10,371
Baluchistan	65.8	33.3	0.9	462
Pakistan	30.0	69.7	0.3	12,283

Pf = *Plasmodium falciparum*; Pv = *Plasmodium vivax*; Mixed = Pv + Pf
Source: GOP 1978

deduce that the high number of cases related to both *Pf* and *Pv* remained almost static (Table 7.4).

Only four of the many vector (*Anopheles*) species are found in Pakistan: *Anopheles culicifacies*, *A. stephensi*, *A. superpictus*, and *A. fluviatilis*. Of these, *A. culicifacies* is regarded as the chief malaria carrier in rural areas and responsible for severe and widespread regional epidemics. *A. stephensi* is the chief vector in urban areas, and breeds in abandoned wells all over the country. *A. superpictus* is found in Baluchistan and Waziristan, whereas *A. fluviatilis* is found in the mountainous regions and forested hills (May 1950). Data estimating vector population were not available, but it was reported that vector density had declined by 1976. This was due to the impact of insecticides such as malathion and sumithion, used instead of DDT and BHC, which seemed to be losing their effectiveness (Shah 1980; GOP 1975).

In view of the country's landscape, malaria is a disease that can claim victims in most parts of Pakistan. The riverine forests, water pools, seasonal flooding,

Table 7.4 Comparative position of various kinds of parasite infection by districts of Sindh, 1976 and 1987

	1976			1987		
Zones	Pf	Pv	Mixed	Pf	Pv	Mixed
Hyderabad	44.9	54.4	0.7	41.5	58.5	0.0
Khairpur	61.9	37.0	1.0	61.4	38.6	0.0
Nawabshah	51.2	46.4	2.3	69.5	30.5	0.0
Sanghar	67.6	32.6	0.4	44.8	55.2	0.0
Tharparkar	46.0	54.0	0.0	23.5	76.5	0.0
Sukkur	34.0	65.0	1.0	64.9	34.2	0.9
Dadu	66.3	31.5	2.2	27.4	72.6	0.0
Larkana	28.2	71.8	0.0	59.7	41.0	0.7
Jacobabad	70.6	28.6	0.8	52.1	47.9	0.0
Thatta	61.5	38.5	0.0	31.3	68.8	0.0
Karachi	18.4	81.6	0.0	42.9	57.1	0.0
Sindh	47.5	51.5	1.0	49.7	50.5	0.2

PF = *Plasmodium falciparum*; Pv = *Plasmodium vivax*.
Source: GOP 1987 (unpublished), Annual Report of Director General Health, Islamabad: Ministry of Health & Social Welfare.

and swampy lands developed in the rainy seasons serve as natural landscape for mosquito breeding. Also, human interventions such as canal irrigation, mismanagement of irrigation water, and cultivation of crops that need standing fresh water (e.g., rice) cause waterlogging, providing suitable aquatic habitats for the breeding of malaria vectors. In light of such features, it may be assumed that malaria would ordinarily be more prevalent in rural areas.

In terms of percentage distribution of its incidence by age and sex, malaria is found to be equally prevalent in both sexes, particularly in the age group between 1 and 15. Children between the ages of 5 and 9 are conspicuously more susceptible to it (Table 7.5). In Baluchistan, malaria seems to be more prevalent among the male working group members of the families. This may be due to greater mobility of the men who are exposed to the risk of being attacked by the malaria vectors (Table 7.5).

Table 7.5 Percentage distribution of malaria by age, sex, and malaria incidence: Pakistan and Provinces, 1982–1983

	Pakistan			Baluchistan			N.W.F.P.		
	Mean	Male	Female	Mean	Male	Female	Mean	Male	Female
All Ages	40.4	41.1	39.6	35.1	35.1	35.2	26.6	27.3	25.9
Under 1	41.7	39.3	44.7	19.3	35.5	3.9	31.9	37.5	23.1
1–4	50.6	48.7	51.7	44.8	47.9	42.7	27.6	26.0	29.5
5–9	54.2	53.3	55.4	41.5	39.0	44.1	37.6	37.2	38.1
10–19	47.9	48.4	47.4	53.0	48.3	60.0	36.6	38.7	33.3
20–29	36.5	39.5	34.1	25.4	34.5	22.7	20.9	17.7	24.1
30–39	33.9	37.9	31.0	17.8	19.1	16.6	26.2	31.0	23.5
40–49	30.1	32.2	28.6	26.0	27.0	25.0	23.2	17.0	27.2
50–59	32.5	35.2	29.7	45.0	50.8	39.8	20.9	27.7	15.3
60–69	26.0	25.2	27.0	10.5	2.0	23.6	15.8	20.0	10.9
70–79	24.5	23.5	26.0	21.4	17.7	24.8	24.8	14.1	19.8
80+	24.0	22.0	27.7	9.4	11.9	*N.A.*	N.A.	N.A.	N.A.

	Punjab			Sindh		
	Mean	Male	Female	Mean	Male	Female
All ages	42.3	43.1	41.5	43.4	43.8	43.1
Under 1	41.6	39.2	44.7	50.2	41.8	57.3
1–4	52.0	51.4	52.7	59.1	55.0	63.4
5–9	56.8	56.1	57.7	57.8	55.0	61.0
10–19	49.4	50.1	48.5	50.5	51.9	51.3
20–29	39.1	41.4	37.3	41.3	51.9	31.9
30–39	35.2	37.7	33.2	36.5	45.4	30.5
40–49	31.5	35.3	29.6	29.3	32.4	25.7
50–59	33.6	36.2	30.7	34.3	33.7	34.8
60–69	29.2	26.9	32.4	23.0	25.2	19.6
70–79	28.1	26.9	30.0	16.0	17.5	13.2
80+	28.4	25.4	34.1	23.7	23.5	24.1

Source: GOP 1986. National Health Survey, 1982–1983

Although malaria incidence is generally higher in rural areas, malaria cases have also been observed in urban centers, particularly in major cities of Pakistan such as Karachi, Lahore, Peshawar, and Quetta, where population has rapidly increased since independence in 1947, but without the corresponding development of proper sanitation measures. Consequently, urban malaria became one of the important factors responsible for setbacks in development efforts of the late 1960s. Therefore, in 1975, the Directorate of Malaria Control included urban areas within its scope as well.

The results of the MEP initiated in 1961 with a view to eradicating malaria from Pakistan by 1974 show that the performance of the program was relatively poor. A variety of social and economic reasons can be ascribed to this lackluster performance, which will be discussed later in the chapter.

Measuring the Intensity of Malaria Resurgence

As in the case of any other hazard, the intensity of malaria is measured in terms of its impact on human life. In other words, the retarding effect of malaria on an individual and/or the community provides an estimate of the intensity of this hazardous disease. Hence, the number of microscopically confirmed malaria cases in various MCZs needs to be computed in relation to the population of the respective MCZs; a measure that is termed here as malaria transmission rate (MTR). This term is being introduced because the term "incidence" is used too loosely in medical geography literature and by medical professionals.

No single event of the resurgence of malaria can depict the pattern of its intensity because, as shown earlier, SPRs vary over time, showing fluctuating periods of waxing and waning of malaria cases, including during the year of lowest occurrence. Obviously, these situations of malaria resurgence must be taken into account in the estimation of the malaria intensity for a given MCZ. Another point that must be considered here is that malaria resurgence is inversely related to the effectiveness of the malaria eradication program. Hence, a good measure of malaria resurgence must not only include the level of resurgence depicted by the peak year situation, but also the trend that follows the peak year, including the year of lowest occurrence of malaria cases, which depicts the point of greatest effectiveness of the MEP.

Following the launch of the MEP in 1961, the exact years of highest and lowest occurrence during the period 1960–1983 were 1972 and 1979, respectively. Since the detailed spatial data for these years were not available, the years 1973 and 1978 were chosen as the closest approximations for the purposes of this study. The level of resurgence of malaria in a given MCZ was measured on the basis of 1973 data, which reflects the high point of resurgence. The trend or direction of malaria occurrence was depicted with the help of a moving average of positive slides for the years 1973, 1975, and 1978 for the same zone. The moving average for each MCZ was standardized using the 1981 population census (GOP 1984b). The resulting measure is termed here as the malaria transmission trend (MTT).

Spatial Trends in Malaria Intensity

The spatial pattern of the level of intensity based on the quartile categories of 1973 MTRs reveals several notable aspects of the dispersion of malaria. In Punjab, with the exception of Jhelum and Rawalpindi, all other MCZs fall into the categories of moderately high to high MTRs. The MCZs with high MTR values extend from the eastern border of Bahawalnagar MCZ, through Sahiwal, Faisalabad, and Jhang, to Sargodha zone in the west, including the northeast zones of Gujarat and Sialkot. The MTRs in this region range from 65 (Bahawalnagar) to 295 (Gujranwala). It is noteworthy that two-thirds of the MCZs in this category have MTRs higher than 100 (Fig. 7.2 and Table 7.6). Thus, the high MTR areas form a compact zone ranging from Punjab in the east to the zones in the northeast of the country.

Areas of moderately high MTT values are found in two parts of Pakistan: one area consists of Lahore MCZ including the districts of Lahore and Kasur, and the other starts from the eastern border districts of RahimYar Khan and Bahawalpur and includes the rest of the central districts and all the districts of western Punjab. These

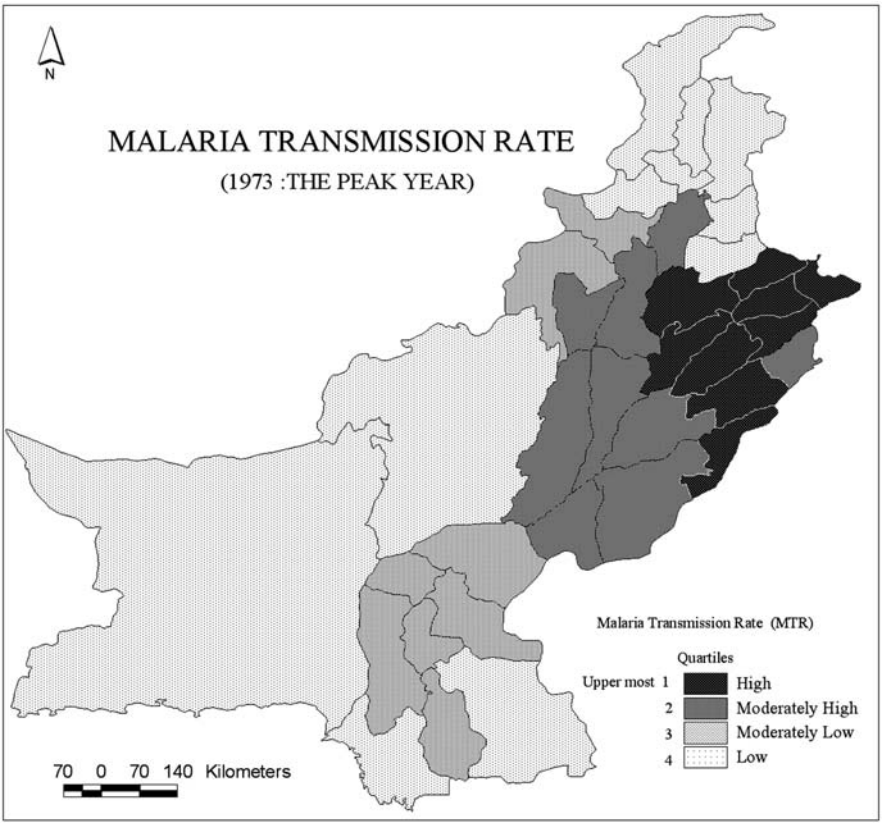


Fig. 7.2 Malaria transmission rate in Pakistan, 1973 (peak year)

Table 7.6 Distribution of the malaria transmission rates (MTR) and malaria transmission trend (MTT): malaria control zones of Pakistan, 1973, 1974, and 1978

	MTR			MTT		MTR			MTT
Malaria Control Zone	1973	1974	1978		Malaria Control zone	1973	1974	1978	
Gujranwala	295.0	15.0	1.0	85.1	Jhelum	11.0	2.0	0.1	3.0
Sheikhupura	222.0	42.0	2.0	52.6	Dadu	11.0	9.0	6.0	6.6
Sahiwal	202.0	55.0	1.0	51.0	Kohat	10.0	3.0	0.3	1.7
Sargodha	184.0	49.0	1.0	48.8	Larkana	9.0	4.0	8.0	6.4
Jhang	162.0	118.0	4.0	57.0	Hyderabad	8.0	1.0	3.0	4.1
Gujarat	106.0	60.0	1.0	35.5	Khairpur	7.0	5.0	15.0	10.1
Sialkot	89.0	33.0	3.0	27.7	Nawabshah	7.0	4.0	3.0	3.7
Faisalabad	71.0	28.0	0.3	22.4	Rawalpindi	7.0	2.0	1.0	2.1
Bahawalnagar	65.0	14.0	7.0	18.8	Bannu	7.0	2.0	2.0	3.0
Multan	61.0	90.0	1.0	12.3	Sanghar	5.0	2.0	2.0	1.5
Lahore	56.0	18.0	1.0	13.9	Sukkur	5.0	3.0	8.0	4.2
R.Y. Khan	46.0	13.0	3.0	12.7	Quetta	5.0	3.0	2.0	2.4
Attock	45.0	14.0	3.0	14.2	Khuzdar	4.0	0.6	1.0	1.7
Muzaffargarh	43.0	15.0	3.0	13.3	Mardan	2.0	0.4	0.2	0.7
Mianwali	41.0	17.0	1.0	11.9	Karachi	1.0	2.0	2.0	1.5
Bahawalpur	29.0	7.0	5.0	9.3	Peshawar	1.0	0.2	0.1	0.4
D. I. Khan	23.0	8.0	1.0	5.0	Swat	1.0	1.0	0.2	1.6
D. G. Khan	13.0	17.0	4.0	29.1	Dir/Chitral	1.0	1.0	0.2	0.2
					Hazara	2.0	0.1	1.0	0.5

Intensity of Malaria Resurgence by Malaria Control Zones (MCZs) Showing Malaria Transmission Rate (MTR) for Different Situations, Mainly Epidemic Years 1973, 1974, 1978 and Moving Average (MTT). Source: Calculated by authors on basis of GOP (1984a) and (1984b).

areas generally comprise intensely affected areas or areas in the first quartile of level of development (Pasha and Hasan 1982; Zaidi 1966).

NWFP is also divided into three distinct regions, ranging from areas with moderately high MTRs, to areas with low MTRs. The MCZ with a moderately high MTR coincides with the D. G. Khan district. The districts adjacent to D. G. Khan up to Peshwar MCZ fall in the category of moderately low MTR. The other low MTR region is formed by Sanghar MCZ. The remaining areas of Sindh represent regions of moderately low MTR.

However, the spatial trend of the resurgence shows some differences as compared to the scenario in the peak year of 1973 (Table 7.6). The Bahawalnagar MCZ showed a decline from high MTR to moderately high MTR, whereas D. G. Khan MCZ emerged in the uppermost quartile. The MCZs of Multan and Mianwali also declined to moderately low MTT levels. The Quetta MCZ, along with several MCZs of Sindh, forms an area of moderately low MTT, whereas Khuzdar MCZ, including Karachi and Sanghar fall in the category of low MTT (Fig. 7.3). It is important to note that Khairpur (with 10.1 MTT) rose to a moderately high MTT level because of its high MTR of 15/10,000 in 1978.

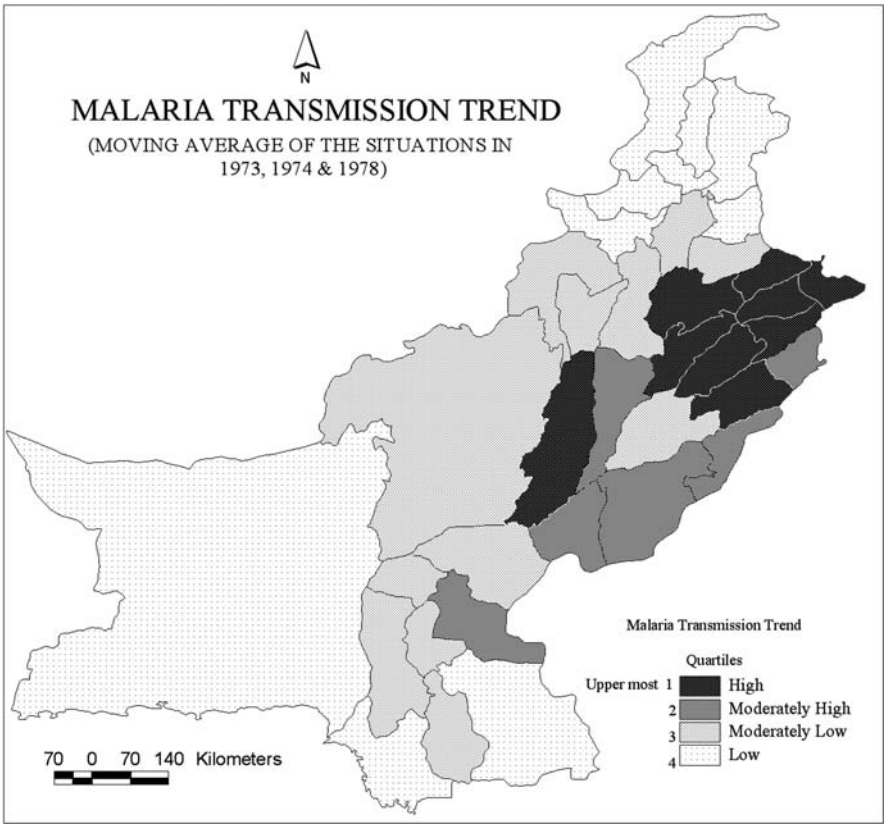


Fig. 7.3 Malaria transmission trend, Pakistan: Moving average 1973, 1974, 1978

The intensity of malaria resurgence for each MCZ can be measured as a summation of the period spanning the peak to the minimum MTR levels. Table 7.7 depicts the pattern of the intensity of malaria resurgence in various MCZs, categorized into quartiles. As in the case of MTRs, the region of high resurgence extends from Bahawalnagar MCZ at the Indian border to Sargodha in the west, including Gujarat and Sialkot MCZs in northeast Punjab. With the exception of Jhelum and Rawalpindi, the remainder of Punjab province falls in the moderately high level of resurgence, that is, in the second quartile. The remaining MCZs of Punjab, NWFP, and Baluchistan retained the same spatial pattern as that of 1973. A moderately low level (third quartile) of intensity existed only in Sindh, where Sukkur MCZ changed due to a higher MTR in 1978 (8.0/10,000 persons) (Fig. 7.4 and Table 7.7).

We found that more than 50% of the population of census years 1972 and 1981 fall in the upper two MTT quartiles, whereas the average MTRs of all the situations are very high. For example, the average MTR in 1973 for the uppermost quartile is 155.5, while the range extends from 65 to 295. Interpreting this situation in the

Table 7.7 Intensity of malaria resurgence in the malaria control zones of Pakistan*

	MTR	MTT	Summation			MTR	MTT	Summation	
Quartile Categories/MCZ	Rank (A)	Rank (B)	Sum	Rank	Quartile categories/MCZ	Rank (A)	Rank (B)	Sum	Rank
Upper Most Quartile (I)					Third Quartile (III)				
Gujranwala	1.0	1.0	2.0	1.0	Dadu	19.5	19.0	38.5	19.0
Sheikhupura	2.0	3.0	5.0	2.0	Larkana	22.0	20.0	42.0	20.0
Jhang	5.0	2.0	7.0	3.5	Khairpur	25.5	17.0	42.5	21.0
Sahiwal	3.0	4.0	7.0	3.5	Jhelum	19.5	25.0	44.5	22.0
Sargodha	4.0	5.0	9.0	5.0	Hyderabad	23.0	23.0	46.0	23.0
Gujarat	6.0	6.0	12.0	6.0	Nawabshah	25.5	24.0	49.5	24.0
Sialkot	7.0	8.0	15.0	7.0	Kohat	21.0	29.0	50.0	25.0
Faisalabad	8.0	9.0	17.0	8.0	Sukkur	29.0	22.0	51.0	26.0
Bahawalnagar	9.0	10.0	19.0	9.0	Bannu	25.5	26.0	51.5	27.0
Second Quartile (II)					Lower Quartile (IV)				
Lahore	11.0	12.0	23.0	10.0	Rawalpindi	25.5	28.0	53.5	28.0
Attock	13.0	11.0	24.0	11.0	Quetta	29.0	27.0	56.0	29.0
Multan	10.0	15.0	25.0	12.5	Khuzdar	31.0	30.0	61.0	30.0
D. G. Khan	7.0	18.0	25.0	12.5	Sanghar	29.0	33.0	62.0	31.0
R. Y. Khan	12.0	14.0	26.0	14.0	Swat	34.5	31.0	65.5	32.0
Muzaffargarh	14.0	13.0	27.0	15.0	Mardan	32.0	34.0	66.0	33.0
Mianwali	15.0	16.0	31.0	16.0	Karachi	34.5	32.0	66.5	34.0
Bahawalpur	16.0	18.0	34.0	17.0	Peshawar	34.5	36.0	70.5	35.0
D. I. Khan	17.0	21.0	38.0	18.0	Dir/Chitral	34.5	37.0	71.5	36.0
					Hazara	37.0	35.0	72.0	37.0

*Intensity of malaria is based on summation of ranks of respective MCZs in terms of 1973 MTR and resulting MTT values. MCZs are grouped in quartiles to indicate intensity.

framework of "game theory" we can assert that the malaria-conducive environment has played a more effective role than have the MEP managers.

The Hypothesis of Malaria Eradication: An Appraisal

Since the resurgence of malaria has been so apparent in a number of other tropical and sub-tropical countries, it appears that malaria cannot be completely eradicated. The wisdom of adopting the idea of "malaria eradication" as the main objective of anti-malaria programs seems to be seriously challenged. It was perhaps in response to this challenge that in 1974, the Government of Pakistan government repealed the Central Malaria Eradication Ordinance of 1960 and also changed the label of MEP to malaria control program (MCP). Consequently, the program was decentralized and handed over to provincial health departments. Thus, as a corollary of malaria resurgence, the important question that arises is, Can we reject the hypothesis that malaria can be eradicated? This section attempts to answer this question.

The hypothesis that malaria can be eradicated was formulated by a WHO expert committee. Its stated goal was "the ending of transmission of malaria and the

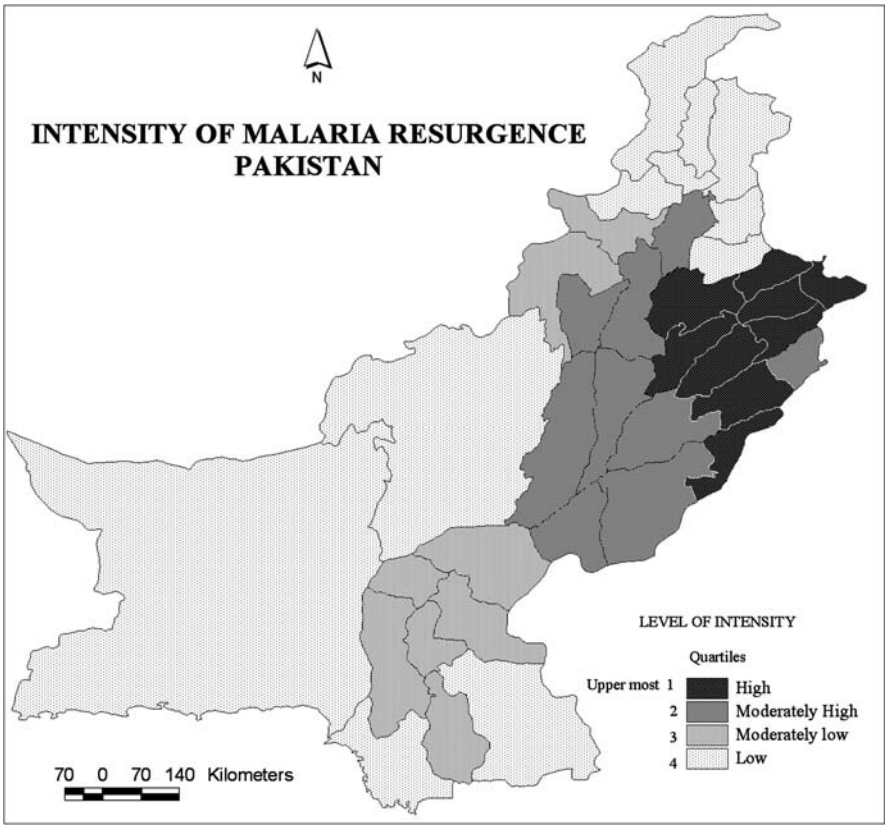


Fig. 7.4 Intensity of malaria resurgence, Pakistan: Moving average 1973, 1974, 1978

elimination of the reservoir of infected cases in a campaign, limited in time, carried to such a degree of perfection that there is no resumption of transmission when the campaign is concluded." (Sixth Report of the WHO Expert Committee on Malaria 1956, cited in Shah 1980, 256).

Events such as the resurgence of malaria and change of label of the program do not necessarily mean the rejection of the hypothesis. The term "control" implies endeavoring to arrive at and maintaining an MTR level below the level of bearable threshold, which was computed by experts as 0.4/1000, equivalent to 4/10,000 (GOP 1978). Thus, in our view, the new label of "MCP" actually complements the MEP by giving a basis for the operational definition of the idea of malaria eradication.

Keeping in view the implementation of MCP and MEP, an operational definition to the hypothesis of malaria eradication could be bringing down the MTR through MEP to a level below the bearable threshold (4/10,000), from where the resumption of transmission of malaria is deemed unlikely unless the MEP managers show negligence and careless behavior. It is with reference to this framework that we appraise

the idea of malaria eradication. Hence, the basic question that needs to be investigated is To what extent of perfection was the MEP carried out? Phrased in terms of the game theory, we need to assess the performance of MEP managers vis-à-vis malaria resurgence.

The goal of MEP was to outwit nature by ending malaria transmission in such a manner that it did not rise again. But the events of 1967 (a malaria resurgence in Karachi) and 1972–1973 (a malaria epidemic in Pakistan) show that MEP managers apparently failed in their aim of outwitting nature. Nevertheless, we cannot deny the fact that it was through the impact of MEP that in 1966, the MTR was brought down to the level below the tolerable threshold (4/10,000) before it started rising again. Similarly, after resurgence, the game was played well by the managers in bringing down MTR to below threshold levels. The MEP managers appeared to develop a more relaxed attitude at the maintenance phase, which gave nature a chance to react. This indicates that the MEP operation itself was possibly technically flawless; the issue was human error. Hence, the overall performance of the MEP needs to be evaluated, as given below.

Evaluation of MEP's Performance

A summative framework is employed for a performance-based evaluation of the MEP's policies/programs. Such an evaluation framework probes the following basic questions: Was the formation of MEP's goal based on proper perception of the problem? How efficient were the strategies selected for achieving the goal? How were the strategies implemented? (Smit and Johnston 1983). A brief discussion within the framework of these questions is presented below.

The most glaring flaw in the perception of malaria in Pakistan was the idea that malaria is primarily a rural disease. This is evident from the image of malaria presented earlier in the overview section, as described by the health planners and MEP experts. Because of this perception, cities and towns were not covered by the MEP. It is important to point out that even after the outbreak of malaria in Karachi in 1967, the MEP continued to exclude urban areas from its scope until 1974, when the disease reached epidemic proportions.

Another illustration of the inefficiency of the MEP's strategy is provided by the manner in which the MCZs and their subsectors were organized. In our view, the system of MCZs carved out by the MEP organizers could not provide adequate infrastructure in any of the MCZs for the effective operation of the program. Matching the MCZs with the respective number of districts in each province would have been more appropriate, i.e., the number of MCZs should be commensurate with the number of districts in each province. For example, in Baluchistan, health planners provided only two MCZs for 17 districts. The districts, as the basic units of administration, can provide better infrastructure for logistic and administrative support than the MCZs, which are rather large areal units.

A variety of technical, operational, organizational, political, and financial factors are ascribed to the ineffective implementation of the MEP. For example, the malaria eradication program considered only those population clusters that had less than 20,000 persons. Similarly, the inefficient phasing of the program created a situation wherein some districts reached the consolidation phase, while others remained in a preparatory stage.

The data based on surveillance activity show microscopically confirmed cases of malarial infection. The detection of malaria cases was done in two ways active case detection (ACD) and Passive Case Detection (PCD). In ACD, trained Malaria Supervisors take blood smears at regular intervals from a history of fever cases. This is done by visiting each house in a subsector. The PCD entails taking blood slides from all the fever cases reported either at health centers or voluntary collaborators (GOP 1978). In both cases, the number of slides showing the positive presence of parasitic infection was clinically treated as the number of actual cases of malaria transmission. However, the total number of blood slides collected from each MCZ was neither proportional to its population nor was it drawn according to any kind of statistically acceptable sampling procedure. Hence, such SPRs were of limited use and could only be recognized as a general review of the situation of malaria resurgence in Pakistan.

Through the later years of the twentieth century, the program continued to be supported largely by foreign funding agencies, a support that had been diminishing over time. Malaria supervisors in many rural areas were responsible for the welfare of populations between 25,000 and 30,000 persons, and areas as large as 40 square kilometers (approximately 15 square miles) without sufficient assistance and logistic support. Also, the escalating cost of insecticides, diminishing international support, poor training opportunities for workers, and low motivation of personnel further compounded the difficulties of running the malaria control program effectively. Other factors that influenced the epidemiology of malaria included fast-changing agricultural patterns, development of new irrigation programs, changing environmental conditions, and the population pressure on natural resources. The growing problem of resistance to insecticides among the mosquito vectors, and the rapidly increasing resistance of *P. falciparum* to chloroquine became matters of great concern, giving rise to expectations of a continued resurgence of malaria and related morbidity and mortality (Khaliq 1988).

The resistance of the mosquito vector to DDT had become apparent to the health planners as early as the time of First Plan, but planners and policy makers did not give it serious consideration. This reveals the lack of interest that the authorities took in MEP's operational efficiency. In the face of such glaring strategic and operational ineffectiveness on the part of MEP in Pakistan, the hypothesis of malarial eradication cannot be dismissed outright. Moreover, it is interesting to note that in 1978 the intensity of MTRs in various MCZs was brought down to a level that can be described as more than satisfactory. The annual MTR in 29 of the 37 MCZs was recorded to be less than the tolerable threshold of 4/10,000, and thus the standard of malaria eradication in these MCZs seemed to have been accomplished.

Conclusions

A spatial analysis of the epidemiological situation of malaria resurgence in Pakistan has been presented in this chapter. The resurgence implies an inverse relationship between malaria cases and the effectiveness of MEP. This concept of resurgence envisages a pattern of interaction between the malarious environment (a suitable environment for malaria transmission) and the MEP within the framework of the game theory. As a second objective, the hypothesis of malaria eradication has been evaluated, taking into consideration the manner in which the MEP was implemented in Pakistan, assuming that the higher the level of malaria intensity the lower the MEP effectiveness.

The study found that areas of high malaria intensity were concentrated in Punjab. The moderately high areas are also generally concentrated in Punjab and Sindh. Paradoxically, these areas generally coincide with the better developed districts of Pakistan, which were effectively covered by the MEP. Because of the generally high intensities of resurgence in these areas, the hypothesis of malaria eradication seems to be seriously challenged.

This study also shows that the performance of the MEP was not entirely satisfactory, particularly in the case of maintaining the bearable threshold that was reached at national scale in 1966. The MEP's objective was formulated on a misleading perception of malaria incidence, which excluded urban areas from its operational framework. The strategies were also poorly designed. However, the resurgence of malaria had its impact on the hypothesis of malaria eradication as is evidenced from the change of label from malaria eradication program (MEP) to malaria control program (MCP), implying that the disease may be controlled but not eradicated. The inclusion of the urban areas within the orbit of MCP furthers this point. But, in view of the MEP's performance data, it is not possible for us to reject the hypothesis that malaria can be eradicated, since it may have been eradicated had the MEP been better implemented. During 1978, in 78% (29 out of 37) of the MCZs, the MTRs were brought down to the level below the bearable threshold. It is important to point out that even in the peak year of the resurgence (1973), there were six MCZs where the MTR had remained below the bearable threshold. Therefore, the hypothesis that malaria can be eradicated may still be valid, given that "eradication" may be described as containment within tolerable levels. The MEP was able to contain the disease, at least in part, and may display more success if effectively implemented.

Acknowledgement The authors gratefully acknowledge the contribution of Ms. Saima Shaikh, Department of Geography, University of Karachi for completing the cartographic tasks in this chapter.

Notes

1. Editors' note: Slide positivity rate is a measure of malaria present in an area calculated as malaria positive slides per 100 blood tests performed. It is also known as spleen rate.

2. Editors' note: The exchange rate in the 1960s was 4.76 Pakistan Rupees per USD due to the Pakistani policy of using fixed exchange rates (see Burney, N.A. and Akhtar, N. Winter 1992, "Government budget deficits and exchange rate determination: Evidence from Pakistan," *Pakistan Development Review*, retrieved June 1, 2009 from BNET Business Publications Website http://findarticles.com/p/articles/mi_6788/is_4_31/ai_n28620545/pg_3/?tag=content;col1
3. For provinces other than Sindh, data on infections by various types of parasites for 1987 was not conveniently available.

References

Frenkel, S. and Western, J. 1988. Pretext or Prophylaxis? Racial Segregation and Malarial Mosquitoes in a British Tropical Colony: Sierra Leone. *Annals of the Association of American Geographers*, Vol. 78, No.2; pp. 211–228.

Gould, P.R. 1963. Man Against his Environment: A Game Theoretic Framework. *Annals of the Association of American Geographers*, Vol. 53, No. 3; 290–297.

GOP 1955. *The First Five Year Plan 1955–60*. Karachi: National Planning Board.

GOP 1960. *The Second Five Year Plan 1960–65*. Islamabad: Planning Commission.

GOP 1965. *The Third Five Year Plan 1965–70*. Islamabad: Planning Commission.

GOP 1975. *Annual Reports of Director General Health, 1973–74*. Islamabad: Ministry of Health & Social Welfare.

GOP1978. *Annual Reports of Director General Health, 1976–77*. Islamabad: Ministry of Health & Social Welfare.

GOP 1979. *Annual Reports of Director General Health, 1977–78*. Islamabad: Ministry of Health & Social Welfare.

GOP 1980. *Annual Reports of Director General Health, 1978–79*. Islamabad: Ministry of Health & Social Welfare.

GOP 1984a. *Annual Reports of Director General Health, 1982–83*. Islamabad: Ministry of Health & Social Welfare.

GOP 1984b. *Census Report of Pakistan 1981*. Islamabad: Population Census Organization, Statistics Division.

GOP 1986. *National Health Survey 1982–83*. Islamabad: Federal Bureau of Statistics, Statistics Division.

GOP 1988. *Pakistan Demographic Survey 1986*. Islamabad: Federal Bureau of Statistics, Statistics Division.

Khaliq, A.A. 1988. Malaria Revisited. *National Health*, pp. 25–27.

May, J.M. 1950. Medical Geography: Its Methods and Objectives. *Geographical Review*, Vol. 40; pp. 9–41.

Pasha, H.A. and Hasan, T. 1982. Development Ranking of Districts of Pakistan. *Journal of Applied Economics*, Vol. 1, No.2; pp. 157–192.

Pinder, R.M. 1973. *Malaria*. Bristol: Scientechnica Publisher Limited.

Shah, K.I., Ahmed, I., Ansari, M.A., and Zaman, S. 1980. *Synopsis of Hygiene and Public Health*. Lahore: Mirza Mohammad Sadiq & Sons.

Smit, B. and Johnston, T. 1983. Public Policy Assessment: Evaluating Objectives of Resources Policies. *Professional Geographer*, Vol, 35, No. 2; pp. 172–178.

Zaidi, I.H. 1966. Toward a Measure of the Functional Effectiveness of a State: The Case of West Pakistan. *Annals of the Association of American Geographers*, Vol. 56, No.1; pp. 52–67.

Chapter 8
Malaria Resurgence in Urban India: Lessons from Health Planning Strategies[1,2]

Rais Akhtar, Ashok K. Dutt, and Vandana Wadhwa

Abstract Urban malaria has become an important issue in the overall strategies in the control/eradication of malaria in India. This chapter highlights the fact that unplanned and haphazard developmental activities have resulted in deteriorating urban environments, which in turn have created conducive breeding areas for certain malaria vectors such as *Anopheles stephensi*. This chapter identifies urban regions where malaria surfaced as early as 1962–1963 and implicates construction activities, green belts, and poor water and drainage conditions in the slums as major factors responsible for the spread of malaria. API rates were used to compare malaria occurrence during 1978 and 1993, finding that the above development activities and population resistance to malaria are two of the important factors in variations in malaria patterns over time and space.

Keywords Malaria eradication · Urban development · *A. stephensi* · Urban ecology · Urban Malaria Scheme (UMS)

Warm, humid climates are optimal breeding grounds for malaria vectors, and this is the major factor responsible for the occurrence and recurrence of this disease in India. The endemic areas of the forested tracts of central, eastern, and southern India, and the marshy tracts of the west have historically been ideal breeding grounds from where malaria spreads to the rest of the country. Although for a long time malaria was believed to be a predominantly rural disease, the larger cities of Bombay and Delhi have experienced it since the early part of the twentieth century (Hodgson 1914). Urban malaria established a hold in a major way in the early 1960s, just when malaria was thought to be under control. By 1965, the country experienced an overall resurgence and urban malaria became a dreadful reality. Urban

R. Akhtar (✉)
Emeritus Scientist, CSIR, Centre for the Study of Regional Development, Jawaharlal Nehru University, New Delhi, India
e-mail: raisakhtar@hotmail.com

R. Akhtar et al. (eds.), *Malaria in South Asia*, Advances in Asian Human-Environmental Research 1, DOI 10.1007/978-90-481-3358-1_8,

development provided an environment conducive for certain vectors of malaria, and over the last few decades of the century, urban malaria fluctuated through a series of combinations of varying intensities and geographical spreads, as presented in this study.

Since the probability of total eradication through vaccination does not seem to be a feasible course of action for now, the same end may be better achieved, or at least attempted, through prevention and control measures that complement and supplement health planning policies. This chapter studies the past trends and patterns of malaria occurrence in order to foster a better understanding of the behavior of this disease and enable health planners to take more effective steps against it. Therefore, the purpose of this study is to trace the patterns of change in the intensity and spread of malaria in urban India in the latter half of the twentieth century, and to explain these particular patterns within their socio-economic and environmental contexts, hoping to better inform health planning actions.

Background and Context of the Study

Malaria Vectors in India and Their Suited Ecology

Only the female *Anopheles* mosquito causes malaria. Of the various *anophelines* found in India, the major malaria vectors are *A. culicifacies*, *A. fluviatilis*, and to an extent, *A. stephensi*. Of these, it is the last that has been of most concern to populations in urban areas. It shifted its ecology from rural environs, where it was mainly zoophilous (feeding on animals), to urban areas, where it is found breeding in areas of construction activity, cisterns and shallow wells, overhead tanks, and slums (see Service 1989). This situation was aptly captured in a quotation by Macdonald (1957), who stated "*A. Stephensi* is highly zoophilic and in the countryside (of Bombay State) conveys a highly unstable malaria or none at all, but within the city, it can find breeding places, and even a small prevalence causes severe (endemic) malaria" (in Batra et al 1979, p. 112).

Urban Malaria: A Historical Review

The history of urban malaria in India can be divided into a series of phases, based upon chronology and related technological advancements that are reflected in the measures adopted to combat the disease.

Phase I—Pre-independence Period (Beginning of the Century Till 1947)

During the first decade of the twentieth century, the city of Bombay in west India was the focus of malaria incidence. According to Turner (1910), Bombay was the world's first city to attempt to combat malaria with modern scientific techniques.

Malarial vectors were also abundant in Delhi as early as 1914. In fact, 13% of the total adult mosquitoes collected in the city represented *A. stephensi*, and the breeding of this species was encountered in used and abandoned wells in both premonsoon and monsoon periods (Hodgson, 1914).

The basic thrust of the anti-malarial programs was to destroy mosquito larvae, both permanent and seasonal (caused by monsoons). Improved sanitation, draining, leveling, filling in, cleaning of wells and tanks, oiling and extermination of mosquitoes were also suggested (Covell 1931). Quinine was used as a curative measure.

Phase II—Period of Active Anti-malarial Drives (1948–1965)

This period itself may be divided into two halves, the first decade of which was more of a stock taking exercise, the second decade being more action oriented. India received a fresh lease of life in 1947 at the time of independence. At this time, malaria was a major cause of mortality and morbidity, causing 800,000 deaths and 75 million more to suffer its ravages (Akhtar and Learmonth 1977). In 1948, the Malaria Survey of India prepared a map of healthy, variable endemic, and endemic areas. Endemic areas are those where malaria exists all year round due to climatic conditions. Ideally, the temperature ranges between 65 and 90°F (approximately 18–32°C), and rainfall typically exceeds 30 in. (about 76 cm).

The Ahmedabad region in the west (the swamps of the Kutch area), the southern Peninsula, Lower Ganges plain, and Northeast India were identified as endemic. The forested tracts of the Ghats, Madhya Pradesh and Orissa hills, and the Assam hills were termed as 'hyper-endemic areas.' Northwest India was characterized as an epidemic area, and the interior peninsula and west India as non-endemic (Dutt et al. 1980).

This categorization was the basis of various anti-malaria drives in 1953, a year that saw the launch of the National Malaria Control Program (NMCP). Encouraged by the success produced by these drives, and synchronizing with WHO's malaria eradication program, the NMCP's anti-malaria drive peaked to a veritable war against the disease by 1958 in the form of the National Malaria Eradication Program (NMEP). This program encompassed house and environ spraying, treatment of infected persons, and distribution of prophylactics. The success rate was a phenomenal 97.9%, with malaria-related mortality declining from 75 million in 1952 to 0.1 million in 1965, which is now known as the trough year of malaria incidence in India (Akhtar and Learmonth 1977; Raghavendra and Subbarao 2002).

However, the focus of this program was on rural areas, as malaria was thought to be a rural disease. Thus, the first signs of urban malaria surfaced as early as 1962–1963, in the four South Indian towns of Visakhapatnam, Guntur, Salem, and Erode. By 1965, this figure had risen to ten cities, though malaria incidence in the country had declined in general. The major factors responsible for the spread of urban malaria are as follows:

1. The increase of developmental activities, both rural and urban, which resulted in conditions suitable for mosquito breeding, e.g., construction activities in urban areas and increased farming activity coupled with irrigation in the rural areas.
2. *A. stephensi*, a malaria vector that had not been particularly dangerous due to its predominantly zoophilous nature, adapted to the new urban ecology and began to breed in cisterns, shallow wells, and overhead tanks abundantly found in urban areas.
3. At the same time, *A. stephensi* and *A. culicifacies*, the two most common urban malarial vectors began to achieve immunity to DDT and the organochlorides BHC/HCH (benzene hexachloride/hexachlorocyclohexane), which were the most popularly used insecticides (Akhtar and Learmonth 1977; Raghavendra and Subbarao 2002).

Phase III—Period of Malaria Resurgence (1966–1977)

In view of the occurrence of malaria in urban areas, the government extended the anti-malaria drive by founding the Urban Malaria Scheme (UMS) in 1971, which in its initial year covered 23 towns, and added five more in the subsequent year (National Vector Borne Disease Control Program [NVBDCP] n.d.; Sharma 1996). According to the NMEP, this helped in checking the incidence of urban malaria down to no more than 1% of the total malaria cases in the country (Kondrashin and Rashid 1987). However, malaria resurgence began due to factors such as (a) the Indo-Pakistan war, which interrupted the program and also caused disproportionate defense spending, (b) overconfidence on part of the government due to the recent success in controlling the disease, and (c) other factors as noted in phase II. This resurgence spread from four major foci: the Kutch salt marsh, and the Madhya Pradesh, Orissa, and Assam Hillforests, because they are inaccessible areas where the full effect of anti-malaria programs had not yet been felt (Akhtar and Learmonth 1977).

There were many fluctuations in the pattern of malaria incidence over the 1965–1976 time span, but by the end, the final scenario showed intensified rates in the northwest, west, and northeast parts of the country. Lower rates of malarial incidence were seen in the traditionally endemic south and southeast, where the population had developed a certain level of resistance to the disease. However, the resurgence of malaria rates from 0.1 million in 1966 to 6.4 million in 1976 led to an in-depth review of the eradication program, and a modified plan of operation (MPO) was introduced in 1977. The basic objectives of the program were the following:

1. Prevention of deaths due to malaria.
2. Reduction of morbidity.
3. Maintenance of the status of industrial development and the “Green Revolution” to promote and retain the success of achieving some ground in the war against malaria.

4. Emphasis on bioenvironmental factors, drug resistance in *P. falciparum*, and organizational and managerial aspects. (Government of India [GOI] 1998; Kondrashin and Rashid 1987; Sharma 1996)

Phase IV—Post-resurgence Period (1978–1993, Study Period)

The above measures led to a significant reduction in malaria within the first 5 years of operation. Malaria cases came down to 2 million cases by the mid-1980s. However, there have been shifts in malaria rates and geographical spreads every few years since then, and these substantially influenced the direction of the health planning measures within which anti-malaria efforts are carried out. For example, the late 1980s saw a surge in malaria incidence due to an epidemic, and the 1990s saw increased intensity in malaria levels. In light of these vicissitudes, an updated anti-malaria policy became operational in the 1990s, but only as of 1995 (after our study period) with the launch of the malaria action plan (MAP) that specified the prioritization of geographic and topical areas of malaria control in form of a manual to be distributed to the states. In consort with WHO guidelines, new criteria were established for identifying urban areas that should fall under the UMS's purview and care, which were as follows:

1. The urban area must already have an existing malaria database of at least a year.
2. The population of the urban area must be a minimum of 50,000, as opposed to 40,000 laid down before.
3. The spleen rates or slide positivity rates (SPR or malaria positive slides per 100 tests) should be 5% or more, and the ratio between clinical malaria cases and fever cases should be 1:3 or greater, as per hospital/dispensary statistics during the last calendar year. SPR is different from the annual parasite index (API), which is positive blood samples in an area divided by population of the area in thousands, required to be 2 per 1,000 or more (GOI 1998, 2006; NVBDCP n.d).

From this background discussion, it is apparent that health planning had taken the aspect of planning for malaria eradication and control in hand. However, constant resurgence proves that it was not adequate and therein lies the significance of this study, in that it studies the shifts in the pattern of malaria incidence in urban India and attempts to understand the same so as to better inform and strengthen future health planning measures.

Research Design and Methodology

The data used in this study comprise the location and APIs of all urban areas covered by the NMEP in 1978 and 1993. APIs are used as a measure of malaria intensity, while location is employed to gauge its spread. The data source was the above-mentioned NMEP.[3] The above points in time are chosen to evaluate the malaria

situation in India after the MPO was launched in 1977, which, as noted before seemed to be effective for a while, but then seemed to lapse. The time point 1978 also allows continuity with earlier studies by the authors, and 1993 was the latest data set available at the time this study was conducted in 1995. The time span is also suitably long enough to enable an adequate depiction of the shifts in malaria occurrence.

This empirical study attempts to reveal the differential rates of malaria intensification and spread over time, despite standard malaria control programs. Toward this end, the analysis employs simple statistical tools and includes possible explanations for such spatio-temporal changes, delving into the issues and implications related to such shifts as explained by the analysis.

The APIs for 1978 were categorized into areas of 'high,' 'medium,' and 'low' occurrence of malaria, where 'high' constituted any API value above the mean. These classes were mapped using the proportional representation technique; a similar exercise was conducted for the 1993 database. A *t*-test was conducted to check for statistical significance in the difference between mean APIs for the 2 years, and the rates of change in malaria intensity were computed using a consolidated database, where only those urban areas were included that appeared in both data sets. This too was plotted on a map, depicting areas of increase, mild decline, and sharp decline. The result is a series of maps depicting the intensity and geographic spread of malaria for the years 1978 and 1993, and the spatial representation of the rate of change of this intensity.

Results and Discussion

Pattern of Malaria Incidence in 1978

The number of urban areas included under the NMEP at this time was 55, and the mean API was 11.51. Table 8.1 presents the names and APIs of these urban areas, and Fig. 8.1 shows the geographic distribution of malaria intensity at this time, as measured by API. The focus of malaria incidence was in the drier, traditionally non-endemic area of northwest India, namely New Delhi and the adjacent belt of newly developing towns in the state of Haryana, and the cities of Chandigarh and Amritsar. Malaria was present in the urban centers of the traditionally endemic areas of the south, but the intensity (i.e., rate of occurrence) was remarkably lower than that in the northwest.

The most probable reasons for higher intensity of malaria occurrence in the northwest are as follows:

1. The populations of the non-endemic areas had lower resistance to malaria and were therefore more vulnerable to the disease. It may be noted that resistance to the malarial parasite in the human body has a span of 8–12 years (WHO 1979; Dutt et al 1980). The southern population held on to that resistance, acquired

Table 8.1 Annual parasite index for selected cities: India, 1978

City	API	City	API
Agra	0.08	Sambalpur	3.73
Calcutta	0.14	Guntur	4.33
Visakhapatnam	0.16	Bikaner	4.57
Warrangal	0.22	Jhansi	4.66
Belgaum	0.30	Ajmer	5.51
Bombay	0.32	Dahod	6.12
Bangalore	0.33	Kota	6.33
Agartala	0.35	Salem	6.90
Bhopal	0.38	Madras	6.98
Ludhiana	0.54	Ferozpur	8.52
Raurkela	0.61	Bhavnagar	9.02
Lucknow	0.72	Jammu	9.38
Hyderabad	1.01	Ahmedabad	10.47
Pune	1.04	Erode	11.63
Daltonganj	1.23	Jalgaon	12.62
Jaipur	1.28	Amritsar	13.31
Meerut	1.38	Jodhpur	13.58
Hazaribagh	1.46	Panipat	17.34
Vellore	1.68	Bokaro	18.31
Ratlam	1.73	Rohtak	24.75
Dhulia	1.74	Patiala	29.23
Bellary	2.04	Bharatpur	34.43
Aurangabad	2.16	Sonepat	36.87
Jalandhar	2.54	Broach	47.94
Tuticorin	2.90	Karnal	54.19
Vijayawada	3.00	Delhi	58.07
Bhuj	3.13	Bhiwani	62.38
		Chandigarh	79.55

Data source: Unpublished reports, NMEP[3].

when malaria was still existent there in the early 1960s (Akhtar and Learmonth 1977).

2. The malaria vector *A. stephensi* had by now adapted very well to its new urban surrounds, breeding in slums, cisterns, overhead water tanks, and other such urban features.
3. This last factor was exacerbated by the fact that the ongoing developmental activities in urban areas were creating more conditions that promote vector breeding. For example, construction activity caused shallow puddles in a myriad of places, providing many breeding areas for the vector. Additionally, the influx of rural labor force not only carried the disease in with them but also created slums, which are ideal breeding grounds for malaria-causing mosquitoes.
4. The Green Revolution was a very strong movement in the northwest part of the country. Despite its rural scope, it contributed to the intensification and spread of malaria in this entire region. This was due to agricultural development activities

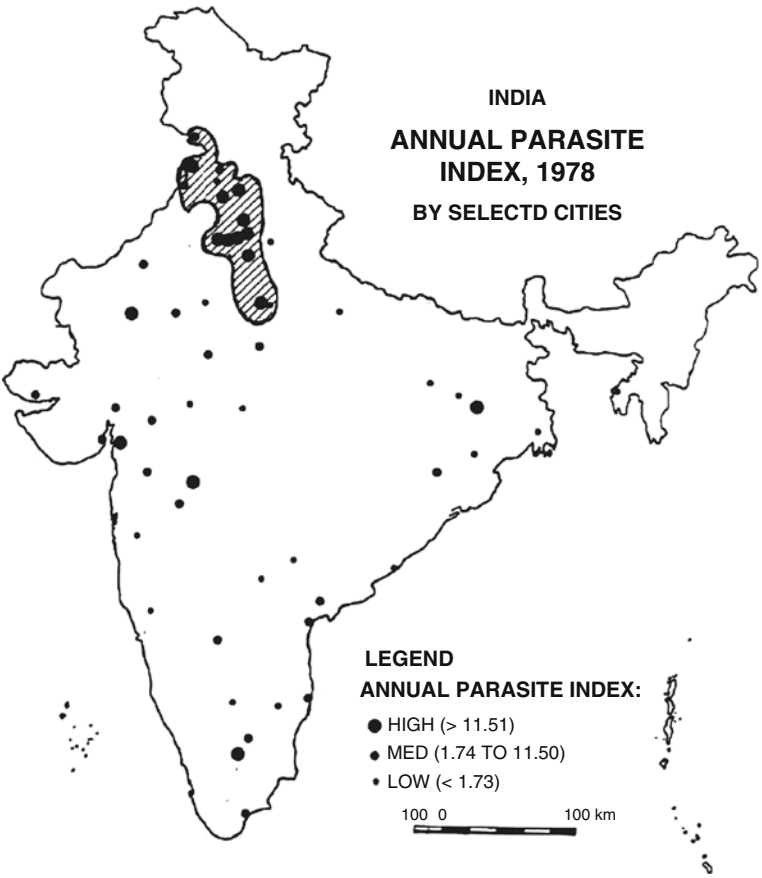


Fig. 8.1 Annual parasite index in selected cities of India, 1978
Data source: Unpublished reports, NMEP[3].

such as canal irrigation, causing the underground water table to rise. This created puddles in some areas, and a suitable environment for mosquitoes to breed. Further, dense vegetation in the fields, and waterlogging and fungi at the banks of the canals aggravated the situation.

Pattern of Malaria Incidence in 1993

By 1993, the malaria scenario was considerably different, as reflected in Fig. 8.2. The number of urban areas now under the wing of the NMEP grew to 86 (for names and APIs of urban areas, see Table 8.2), revealing the spatial spread of the disease. However, the mean API plummeted to 3.77, reflecting a general decline in the intensity of malaria in urban India. This difference in mean APIs is also statistically significant, as shown by the *t*-value in Table 8.3. However, the regional polarity

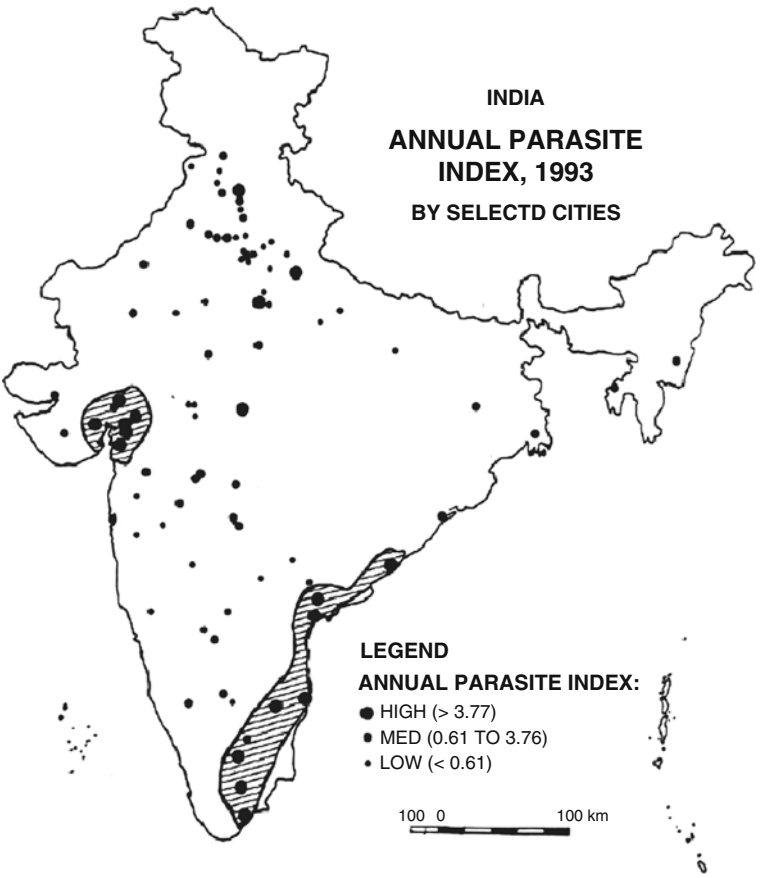


Fig. 8.2 Annual parasite index in selected cities of India, 1993
Data source: Unpublished reports, NMEP[3].

remained as strong as ever, although there was a reversal of roles in the focus of occurrence.

The traditionally endemic areas re-emerged as centers of urban malaria, i.e., the Ahmedabad region in the west (including the urban areas of Gandhinagar, Rajkot, Anand, and Broach), and southeast India (Vijayawada, Guntur, Madras, Vellore, etc.).

This spatial pattern of malaria occurrence was mainly due to the following factors:

1. The ever-conducive climate of this part of the country that renders it endemic, causing malaria to be present throughout the year.
2. The resistance of the population had passed the 12-year mark, and they were prone to the disease again, as well as having added new members to the population who were most susceptible to malaria, i.e., children under 5 years of age.

Table 8.2 Annual parasite index by selected cities: India, 1993

City	API	City	API
Varanasi	0.00	Delhi	0.98
Belgaum	0.00	Patiala	1.01
Raichur	0.01	Jodhpur	1.05
Jalandhar	0.02	Hissar	1.12
Meerut	0.02	Aurangabad	1.19
Khammam	0.03	Akola	1.31
Kanpur	0.03	Ahmedabad	1.33
Ghaziabad	0.04	Bokaro	1.33
Lucknow	0.04	Bhiwani	1.75
Ajmer	0.04	Rohtak	1.81
Pune	0.05	Karnal	1.86
Ujjain	0.05	Jhansi	1.90
Moradabad	0.06	Salem	1.94
Yamunanagar	0.06	Bombay	2.00
Bulandshahr	0.08	Parbhani	2.02
Jaipur	0.08	Sirsa	2.27
Agra	0.10	Kota	2.46
Bangalore	0.13	Gandhidham	2.52
Solapur	0.19	Bhusawal	2.69
Indore	0.20	Dhulia	3.14
Amritsar	0.21	Rajkot	3.48
Faridabad	0.21	Bellary	3.54
Ludhiana	0.28	Jalgaon	3.68
Ahmednagar	0.30	Calcutta	3.75
Sonepat	0.31	Nanded	3.76
Warrangal	0.35	Bhopal	3.94
Muzaffarnagar	0.37	Vellore	4.83
Gurgaon	0.42	Guntur	5.53
Hospet	0.45	Anand	5.62
Mathura	0.47	Broach	7.31
Hyderabad	0.54	Gandhinagar	7.61
Panipat	0.55	Badaun	8.89
Bhavnagar	0.58	Bharatpur	10.24
Nasik	0.59	Erode	10.28
Ratlam	0.60	Chandigarh	10.79
Agartala	0.67	Surendranagar	11.97
Hoshiarpur	0.75	Madras	11.98
Tumkur	0.76	Vijayawada	12.12
Berhampur	0.78	Nadiad	14.93
Imphal	0.79	Visakhapatnam	15.27
Hassan	0.88	Godhra	23.47
Ambala	0.92	Tuticorin	40.01
Bikaner	0.96	Dindigul	51.85

Data source: Unpublished reports, NMEP[3].

The northwest region displayed a decrease in rate of urban malaria, but an increase in the number of cities affected by it. The major causes for this pattern are the following:

Table 8.3 *t*-Test of urban annual parasite indices for 1978 and 1993, India

t-Test/pairs 1978–1993							
Variable	Number of cases	Mean	Standard deviation	Standard error			
1978	47	12.6801	19.221	2.804			
1993	47	3.6708	6.641	0.969			
(Difference) mean	Standard deviation	Standard error	Corr.	Two-tailed probability	*t*-Value	Degrees of freedom	Two-tailed probability
9.0093	20.020	2.920	0.050	0.738	3.09	46	0.003

1. The fall in malaria rates could be attributed to the fact that this area received greater attention by virtue of its being close to a major administrative and economic center, the capital city of New Delhi.
2. Another major factor for this decline in malaria intensity was the building up of resistance against this disease due to the past spurt of malaria incidence.
3. The spatial spread of malaria is mainly due to the increase and spread of developmental activity, and the associated conditions that foster malaria vector breeding. In fact, it is interesting to note that the corridors of urban malaria spread are congruent to the corridors of urban development radiating from the Delhi region.

Spatio-temporal Change in Malaria Intensity Over 1978–1993

Table 8.4 and Fig. 8.3 vividly depict the shifts in the intensity and spread of urban malaria over the 1978–1993 time period. The urban areas of the southeast region displayed an intensification of urban malaria, reverting to their roles as centers of diffusion, although the malaria rates were not as high as they were in 1948 (refer description of map by Malaria Survey of India above). The northwest region showed a decline in malaria intensity by individual centers, but a spread is apparent in geographical or areal terms.

The reasons for these differential rates and spreads are mainly the aforementioned partiality toward the northwest, which is also related to increased developmental activity in this particular region. Also, the development of resistance against malaria in the northwest led to a decline in malaria rates, though the disease spread to a greater number of urban areas. The reasons for this spread is primarily the conducive conditions for vector breeding due to developmental activities per se and secondarily, the transmission of the disease through small-scale migrations of the labor force. In the southeast and west, the cycle of malaria is played again and again as the endemic area remains ever-prone to this age-old disease.

Table 8.4 Rate of change in annual parasite index by selected cities: India, 1978–1993

City	Rate of change	City	Rate of change
Jalandhar	–99.41	Jalgaon	−70.83
Ajmer	–99.20	Bharatpur	−70.26
Sonepat	–99.15	Ratlam	−65.45
Meerut	–98.84	Kota	−61.14
Belgaum	–98.66	Jhansi	−59.33
Amritsar	–98.46	Bangalore	−58.77
Delhi	–98.31	Ludhiana	−48.04
Bhiwani	–97.19	Hyderabad	−46.27
Panipat	–96.81	Aurangabad	−45.15
Karnal	–96.58	Erode	−11.65
Patiala	–96.54	Guntur	27.76
Pune	–95.46	Agra	36.84
Lucknow	–94.31	Warrangal	58.99
Jaipur	–94.06	Madras	71.56
Bokaro	–92.76	Bellary	73.23
Rohtak	–92.68	Dhulia	80.59
Jodhpur	–92.28	Agartala	91.93
Bhavnagar	–90.29	Vellore	187.67
Ahmedabad	–87.34	Vijayawada	304.07
Chandigarh	–86.43	Bombay	527.59
Broach	–84.76	Bhopal	937.89
Bikaner	–79.03	Tuticorin	1279.59
Salem	–71.87	Calcutta	2675.56
		Visakhapatnam	9505.66

Data source: Calculated from unpublished reports, NMEP[3].

Conclusion: Planning, Prevention, and Cure

The preceding discussion reveals that there was a differential rate of malaria intensity and spread over the country, reflected in the northwest/southeast dichotomy in the pattern of malaria incidence. On the one hand, the northwest region's malaria intensity had declined considerably, but areal diffusion had taken place. On the other hand, the southeast has experienced a sharp resurfacing of the disease, although in 1978 it had displayed depressed rates of malaria. This study has also shown that despite eradication and control measures taken by the National Malaria Eradication Program in India, the disease still evades efforts toward total eradication due to several factors, such as the prevalent climatic conditions that are conducive to mosquito breeding, and economic and technological constraints. Moreover, this disease is now widespread in urban India where construction activities, green belts in cities, and slum areas simulate the rural environment and provide excellent breeding conditions for *A. stephensi,* which is the major malaria vector in urban India. Alarmingly, this vector is fast acquiring immunity to the more popular preventive and curative substances used to contain malaria.

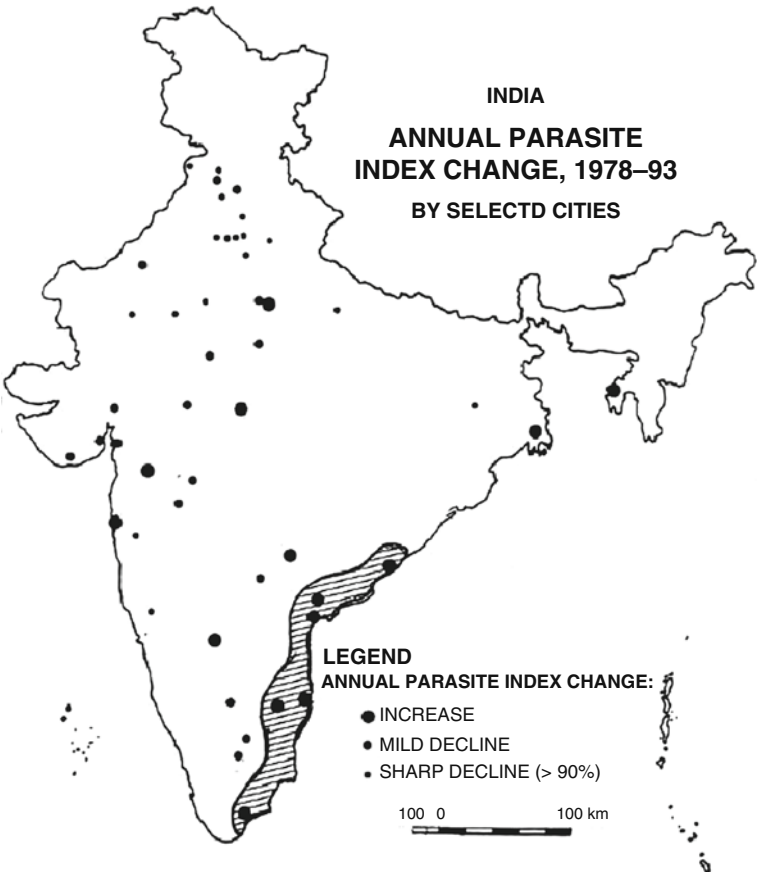


Fig. 8.3 Annual parasite index change in selected cities of India, 1978–1993
Data source: Calculated by authors from unpublished reports, NMEP[3].

However, it is not plausible to wait for a permanent measure such as a vaccine such as that used for smallpox because of the very nature of the malaria parasite, which possesses the capacity to 'disguise' itself from the antibodies by changing its complex protein structure (see Chapter 1). The fact remains that less developed tropical and semi-tropical countries possess a suitable ecology for endemic malaria (Dutta and Dutt 1978). A majority of the population remains threatened by malaria because they cannot always afford certain preventive measures such as mosquito nets and door screens, or facilities such as prompt and effective medical care that are more accessible to the populations of more developed countries. In tropical areas, the immunity of the vector to DDT used for mosquito control and of the parasite to chloroquine used to treat infected persons are other factors that retard malaria eradication (Hudson 1995). Additionally the vector shows signs of developing resistance to other alternative drugs as well (see Chapters 1 and 10).

The resurgence of malaria has been an unpleasant experience, and the fact that urban India is the hub of the country's economy underlines the importance of studying this phenomenon. It is essential to study the pattern of malaria incidence in urban India because the variations in malaria intensity over space and time have a profound effect on the thrust and direction of the strategies that need to be formulated. The fact remains then that until a cheap and effective vaccine is discovered health planning measures consisting of meso- and micro-level control and prevention strategies will have to be formulated in order to strengthen the ongoing programs even further. These strategies will have to run the gamut from vector control at the various stages of its life cycle, to disease surveillance efforts, to appropriate prophylactic measures at both public health and medical fronts.

> Everything about malaria is so moulded and altered by local conditions that it becomes a thousand different diseases and epidemiological puzzles. Like chess, it is played with a few pieces, but is capable of an infinite variety of situations.
>
> Hackett (1937, 266)

Notes

1. Modified from Rais Akhtar, Ashok Dutt and Vandana Wadhwa. 1998. Health Planning and the Resurgence of Malaria in Urban India. Allen Noble, Frank Costa Ashok Dutt and Robert Kent (eds.), *Regional Development and Planning for the 21st Century: New Priorities, New Philosophies*. Aldershot, Hants, England: Ashgate Publishing Ltd. Used with permission.
2. The original data set and analysis of the study conducted in 1995 has been retained, but the text has been updated to reflect new information available to authors since then.
3. Data for APIs in urban areas were retrieved from unpublished reports of the NMEP. We are thankful to the Director, NMEP (now National Vector Borne Disease Control Programme or NVBDCP) for providing necessary data from these unpublished reports of the NMEP, Ministry of Health and Family Welfare, New Delhi, India.

References

Akhtar, R., and Learmonth, A.T.A., 1977. The Resurgence of Malaria in India 1965–1976. *GeoJournal*. Vol. 1, No. 5, 69–80.

Batra, C.P., Reuben, R., and Das, P.K. 1979. Urban Malaria Vectors in Salem, Tamil Nadu: Biting Rates on Man and Cattle. *Indian Journal of Medical Research*. 70(suppl), Dec, pp. 103–113.

Covell, G. 1931. *Malaria Control by Anti-Mosquito Measures*. Calcutta: Thacker, Spink and Company, Ltd.

Dutt, A.K., Akhtar, R. and Dutta, H.M. 1980. Malaria in India with Particular Reference to Two West-Central States. *Social Science & Medicine*. Vol. 14d, 317–330.

Dutta, H.M. and Dutt, A.K. 1978. Malarial Ecology: A Global Perspective. *Social Science & Medicine*. Vol. 12, 69–84.

Hackett, L.W. (1937). *Malaria in Europe*. London: Oxford University Press.

Hodgson, E.C. 1914. Malaria in the New Province of Delhi. *Indian Journal of Medical Research*. Vol. 2, 405–455.

Hudson, L. 1995. First Malaria Vaccine Trial Results Prove Disappointing in Gambia. *India Abroad*. September 15, 46.

GOI. 1998. *Annual Report for the year 1997–98*. New Delhi: Ministry of Health and Family Welfare. Now available at Ministry of Health and Family Welfare website at http://mohfw.nic.in/reports/1997–98Er/Part2Chapter4.pdf

GOI, 2006 *India 2006*. New Delhi: Ministry of Information and Broadcasting.

Kaberia, K. 1994. Super Rice Can Feed a Half Billion More People. *Insight of the News*. Vol. 10, Dec 12, 32.

Kondrashin, A.V., and Rashid, K.M. (eds.). 1987. *Epidemiological Considerations for Planning Malaria Control in South East Asia Region*. New Delhi: WHO, SEARO.

Nowak, R. 1995. How the Parasite Disguises Itself. *Science*. Vol. 269, Aug, 755.

Raghavendra, K. and Subbarao, S.K. 2002. Chemical Insecticides in Malaria Vector Control in India. *ICMR Bulletin*, Vol. 32, 10.

Russell, P.F. 1955. *Man's Mastery of Malaria.* London: Oxford University Press.

Service, M.W. 1989. *Demography and Vector-Borne Diseases*. Boca Raton, FL: CRC Press.

Sharma, V.P. 1996. Re-emergence of Malaria in India. *Indian Journal of Medical Research*, Vol. 103, No. 1: 26–45.

Turner, J.A. 1910. Malaria in Bombay from 1901 to 1910. *Paludism*. No. 1, 39–40.

WHO. 1979. Seventeenth Report of the Expert Committee on Malaria. *Technical Report Series*, *640*. WHO, Geneva.

WHO/SEARO n.d. *Malaria Situation in SEAR Countries, India*. Retrieved November 8, 2007 from WHO/SEARO website http://www.searo.who.int/EN/Section10/Section21/Section340_4021.htm

Chapter 9
The Dynamics of Urban Malaria in India: An Update

Vandana Wadhwa, Rais Akhtar, and Ashok K. Dutt

Abstract This chapter highlights the ways in which urban malaria in India continued to be a source of great concern to the government, health planners, and related officials all the way into the early 1990s. It updates the scenarios described and analyzed in the previous chapter up to the year 1997, the latest year of the twentieth century for which urban malaria data were available to the authors. The previous chapter was founded upon a matrix of malaria and health planning history in India up to the year 1995; the present chapter updates the same but also uses the relationship between urban ecology and malaria occurrence as its foundation. It proposes cycles of malaria resistance and regional occurrence as explanatory mechanisms of spatio-temporal patterns of malaria occurrence.

Keywords Urban ecology · Kolkata · Cycle of resistance · Cycle of regional occurrence

Urban Ecology and Malaria

One of the earliest literary references to urban malaria in colonial India is in the work of the Bengali poet Iswar Chandra Gupta, who wrote the following lines nearly 200 years ago: 'Rete masha, dine machi, Ei niye Kolkata achhi. . .' This may be roughly translated as 'We live in Kolkata (erstwhile Calcutta) with buzzing flies by day and mosquitoes at night. . .'[1]

Kolkata is surrounded by water bodies, and during the rainy season it becomes a city with a swamp-like environment, a major breeding ground for mosquitoes. As such cases of urban malaria became more prevalent in the first third of the twentieth century, the need was felt to adopt control and management methods to contain the disease. One such method was the intra-urban water management scheme as suggested by Sir Patrick Hehir[2] in 1927:

V. Wadhwa (✉)
Department of Geography and Environment, Boston University, Boston, MA, USA
e-mail: vandanaw@comcast.net

R. Akhtar et al. (eds.), *Malaria in South Asia*, Advances in Asian Human-Environmental Research 1, DOI 10.1007/978-90-481-3358-1_9,

> A special branch of the sanitary staff should be daily and continuously employed in systematically treating every pool, pond, tank or drain breeding *Anopheles* with petroleum, and in such a manner as to cover the whole surface of the infected water lying in it once a week during the breeding season of the *anophelines*. The adoption of this measure should be supported by power to prosecute the occupier of any premises on which mosquito larvae are found. Such legislation now exists in various malarious countries. The sanitary establishment of towns should see that owners and occupiers of houses and land keep their premises free from mosquito breeding places; keep water courses and floodwater drains and culverts clear, properly graded, in good condition, and free from vegetation, and if pools are found in them apply petroleum, clear away undergrowth, long grass and jungle within the boundaries of the town, and make arrangements for clearing the land outside the municipal boundaries for 500 yards; fill out or drain excavations, pools and low lying lands, where water is likely to lodge... care should be taken in regard to leveling the area from which the earth is removed (p. 370).

Hehir (1927) also suggested the establishment of a 'Town Mosquito Brigade' in every municipality:

> . . . whose members [the brigade's] visit regularly once a week, the compound of every house in town, and do away with every pool and collection of unnecessary water which can harbour mosquito larvae; to oil every collection of water which is too large to be destroyed; to remove all broken tins, pots, bottles, etc. which can contain water and harbour larvae (p. 372).

Further, 'The government must not allow "wet" cultivation in towns, and rice should not be grown within a kilometer [approximately 0.6 miles] of their outer boundary, and then only if adequate arrangements are made for draining the effluent from the fields.' (Hehir 1927, 372). These strict measures are still required to combat the resurgence of urban malaria in India. In fact, even in the 1990s, many urban areas, particularly smaller towns, still included rice-growing areas or other cultivation plots within their municipal limits (see WHO 2006), rendering the above-suggested actions still relevant.

According to Hehir (1927), the aforementioned malarious conditions in Kolkata were a result of the extensive marshes and rice-growing areas that surrounded it. Its later industrial ecology and the proliferation of slums added to these conditions that are so conducive to the disease. Such a relationship between the occurrence of urban malaria and the ecology of the urban area has been dealt with in a WHO Expert Committee Report on Malaria (WHO 1995, cited in the Annual Report, 1997–98 of the Ministry of Health and Family Welfare, Government of India [GOI] 1998).

According to another report (Shiv Lal et al. 1998),

> [In] most urban areas 30–40 per cent of the population live in hutments and in the peri-urban areas. In other settlements water supply and drainage are both inadequate resulting in unhygienic living [conditions]. Peri-urban ecotype has emerged as a new malaria paradigm the control of which requires the implementation of legislative measures. This is lacking except in a few towns (p. 89).

As given in the previous chapter, the Urban Malaria Scheme (UMS) set up for malaria control used the following criteria for inclusion of a town under its purview:

(a) Population more than 50,000 persons and
(b) SPR of 5% or more (as opposed to the previous 10%) or case proportion of fever cases more than 30% (GOI 1998).

These criteria ensured the inclusion of a larger number of urban areas under the UMS for malaria control practices. In 1997, the government launched an Enhanced Malaria Control Project (EMCP) with the aid of the World Bank, which identified 19 main cities/towns in 10 states severely affected by malaria to be specifically targeted for anti-malaria drives (GOI 1998)—Kolkata was one of these, the only city in West Bengal still suffering from the scourge of malaria. Table 9.1 lists these urban areas that are considered to be malaria prone due to their particular ecologies.

Also recommended as part of the EMCP were (i) a more effective case detection mechanism, (ii) the opening of fever treatment depots in slum areas at the rate of one depot per 2,000 population, and (iii) the ready accessibility of anti-malarial drugs through the creation of Drug Distribution Centers. Meanwhile, the reach of the UMS itself had extended to 131 urban areas of its target of 181 such cities/towns (GOI 1998). Results were very rewarding; morbidity declined from 2.66 million in 1997 to 1.82 million in 2004, and APIs fell from 2.86 to 1.74 (GOI 2006).

In 1999, the NMEP was reenergized and renamed the National Anti-Malaria Programme (NAMP), following a strategy encompassing (i) early case detection and prompt treatment (EDPT), (ii) selective vector control, (iii) personal protection, and to a degree, the use of intermittent preventive treatment (IPT). However, since

Table 9.1 Urban areas selected from the urban malaria scheme for enhanced malaria control project: India, 1995

State	Urban area	Ecology
Andhra Pradesh	Visakhapatnam	Industrial
	Hyderabad	Industrial
Bihar	Chaibasa	Forest
Gujarat	Bharuch	Industrial
	Dohad	Industrial
	Godhra	Industrial
	Vadodara	Industrial
	Ahmedabad	Industrial
Madhya Pradesh	Bhopal	Industrial
Maharashtra	New Mumbai	Newly developed area and industrial town
Orissa	Sambalpur	Industrial
Rajasthan	Jodhpur	Flooding during rainy season
	Bharatpur	Flooding during rainy season
Tamil Nadu	Madras	Newly developed area and industrial town
	Tuticorin	Industrial
	Erode	Industrial
	Dindigul	Industrial
Karnataka	Bellary	Industrial
West Bengal	Calcutta	Industrial, slum ecology

Data Source: Shiv Lal et al. (1998).

many of India's related health drives were fragmented over various departments and divisions, the consolidated National Vector-Borne Disease Control Programme (NVBDCP) was founded in 2003 under the aegis of the Ministry of Health and Family Welfare. Among other aspects of malaria, its aim was also to avail the population of ACTs to offset the resistance of the *plasmodium* to chloroquine and sulphadoxine-pyrimethamine (SP). Attention to malaria in urban areas was also made a priority (Agrawal 2008).

With all of these initiatives since the 1990s, it is heartening to note that the proportion of urban malaria cases to total cases has been on the decline since then, and particularly since 1993 (see Table 9.2). It makes appropriate a more detailed study of the urban malaria situation in India since 1993, where the previous chapter left off. The following sections deal with the malaria scenarios in urban India in 1994 and 1997, the latter being the latest year of the twentieth century for which urban malaria data were available.

Table 9.2 Proportion of urban malaria cases to total cases: India, 1990–1997

Year	Urban to total malaria cases (%)
1990	10.72
1991	10.07
1992	9.20
1993	10.04
1994	9.09
1995	8.07
1996	7.79
1997	3.05

Notes: Data only for cities/towns under UMS; 1997 figure is provisional.
Source: Shiv Lal et al. (1998), p. 44.

Data and Methodology

This chapter studies the patterns of malaria occurrence through the time period 1994–1997, using these two time points as snap shots of malaria intensity and distribution in urban India in relation to the situation depicted in Chapter 8. While this chapter covers a seemingly short period of 4 years, it enables the total time periods covered by the two chapters to span almost two decades, revealing two interesting phenomena that govern malaria occurrence and recurrence in urban India: (a) the cycle of resistance and (b) the cycle of regional occurrence.

The previous chapter entailed a city scale in-depth analysis, but this chapter is based on a wider state level analysis due to constraints of data availability. However, it is possible to discern a general spatial pattern on the basis of the aggregate state level data (see section on 'Some Notes on Methodology' below). Furthermore,

Table 9.3 Urban malaria in India by selected states: 1994 and 1997

Region	State	1994 Total positive cases	P.f. cases	1997 Total positive cases	P.f. cases
North	Bihar	311	34	40	15
	Haryana	3701	289	20617	275
	Punjab	1248	6	1763	0
	Uttar Pradesh	3345	345	1271	105
	Jammu & Kashmir	31	0	53	2
	Delhi	7229	47	1	0
	Chandigarh	7953	59	1819	318
South	Andhra Pradesh	37867	818	3195	64
	Karnataka	4238	248	4286	164
	Tamil Nadu	65228	2557	16076	485
East	Manipur	466	193	61	20
	Nagaland	429	151	436	164
	Orissa	4178	3413	1464	991
	West Bengal	18297	2283	4493	117
	Tripura	181	72	24	16
West	Gujarat	29005	7578	4075	285
	Maharashtra	28791	5889	7872	864
	Rajasthan	3730	1855	372	2
Central	Madhya Pradesh	10307	3361	3836	1125
Total		226535	29198	71754	5012

Source: Shiv Lal et al. (1998), Appendix IV.

comparability between the two analyses is facilitated by retaining Annual Parasite Index (API) as the unit of measurement of malaria intensity.

Table 9.3 shows the number of positive malaria cases and *Plasmodium falciparum* cases in urban areas (aggregated to state level figures) for the years 1994 and 1997 in states for which such data were available. The data are limited to these particular 17 states and 2 Union Territories since the UMS operates only in these areas (GOI 1998). The number of positive cases of malaria for 1994 and 1997 were converted to API using population projections for the respective years calculated from base population figures and growth rates reported in the 1991 Census of India. The API values for 1994 and 1997 are given in Tables 9.4 and 9.5, respectively. Data source for number of urban malaria cases and *P. falciparum* (*Pf*) cases was the NMEP[3] and for projection of 1994 and 1997 population figures were state-wise general population tables from the *1991 Decennial Census of India* (GOI 1991).

Figures 9.1 and 9.2 depict the state-wise distribution of APIs for 1994 and 1997, respectively. It is apparent that the distribution is skewed (thus the use of a logarithmic scale in the bar graphs), with Chandigarh far exceeding the range of data, and the entire distribution having a high standard deviation from the mean—standard deviations are 2.47 around a mean API of 0.83 for 1994, and 0.54 around a mean API of 0.23 for 1997.

This skewedness had two consequences for the analysis:

(a) Chandigarh had to be excluded from all following analyses to remove data bias and was included again only in the final categorization, and
(b) The categorization of the API figures had to be restricted to 'high' and 'medium to low' as opposed to the three categories of 'high,' 'medium,' and 'low' used in Chapter 8. This was done to remove problems of a more subjective interpretation of API figures into such categories. In this case, any figures above the mean (i.e., above average) were categorized as 'high,' which is similar to the categorization of 'high' in the previous chapter, thus retaining comparability of data and analysis (also see section on 'Some Notes on Methodology').

The proportion of *P. falciparum* cases is included in the analysis because the malaria caused by this *plasmodium*, although not as common as *P. vivax*, is more

Table 9.4 Urban annual parasite index for selected states: India, 1994

State	1994 API
Bihar	0.003
Jammu and Kashmir[4]	0.004
Uttar Pradesh	0.022
Punjab	0.058
Tripura	0.059
Rajasthan	0.078
Karnataka	0.089
Orissa	0.124
Madhya Pradesh	0.144
Haryana	0.207
Manipur	0.233
West Bengal	0.250
Nagaland	0.301
Maharashtra	0.338
Andhra Pradesh	0.530
Gujarat	0.659
Delhi	0.660
Tamil Nadu	1.115
Chandigarh	10.943
Total	15.818
Mean	0.833
StdDev	2.465
Excluding Chandigarh	
Total	4.875
Mean	0.271
StdDev	0.297

Data source: NMEP[3] and Census of India 1991.

Table 9.5 Urban annual parasite index for selected states: India, 1997

State	1997 API
Delhi	0.000
Bihar	0.000
Jammu and Kashmir	0.006
Tripura	0.007
Rajasthan	0.007
Uttar Pradesh	0.008
Manipur	0.028
Orissa	0.041
Andhra Pradesh	0.042
Madhya Pradesh	0.049
West Bengal	0.057
Punjab	0.077
Karnataka	0.084
Maharashtra	0.086
Gujarat	0.087
Nagaland	0.260
Tamil Nadu	0.263
Haryana	1.065
Chandigarh	2.210
Total	4.376
Mean	0.230
StdDev	0.537
Excluding Chandigarh	
Total	2.166
Mean	0.120
StdDev	0.248
t-Test	0.095

Data source: NMEP[3] and Census of India 1991.

dangerous than the latter, being more often the cause of cerebral malaria and malaria mortality (Dutt, Akhtar and Dutta 1980; Akhtar and Learmonth 1986; Sharma 1999). Therefore it is an important component of an analysis of urban malaria. In fact, the NMEP saw fit to include within its modified plan of operation (see Chapter 8), a component of anti-malaria drives called the *P. falciparum* Containment Programme (*Pf*CP) that could tackle malaria caused by this deadly *plasmodium* (GOI 1998; Sharma 2003). Table 9.6 provides information on the proportion of *P. falciparum* cases to positive malaria cases for 1994 and 1997, as well as the rate of change in this proportion. Again, it is only the above-average proportion that is of greater interest at this point, when only aggregate level data are available and a more general analysis is preferable. Both malaria intensity (API) and proportion of *P. falciparum* cases were mapped for the selected states for 1994 and 1997 using ArcGIS to provide a spatial representation of the pattern of urban malaria in India.

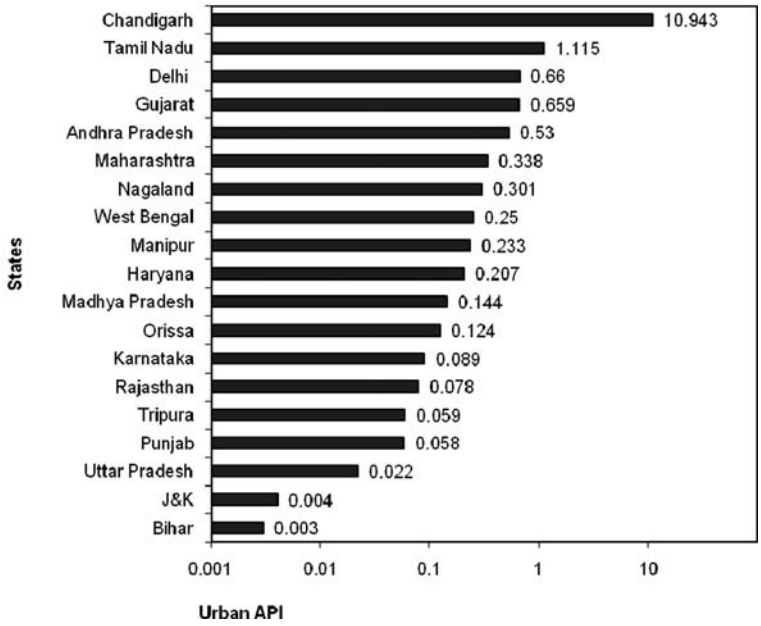


Fig. 9.1 Urban annual parasite index for selected states: India, 1994
Data source: NMEP[3].

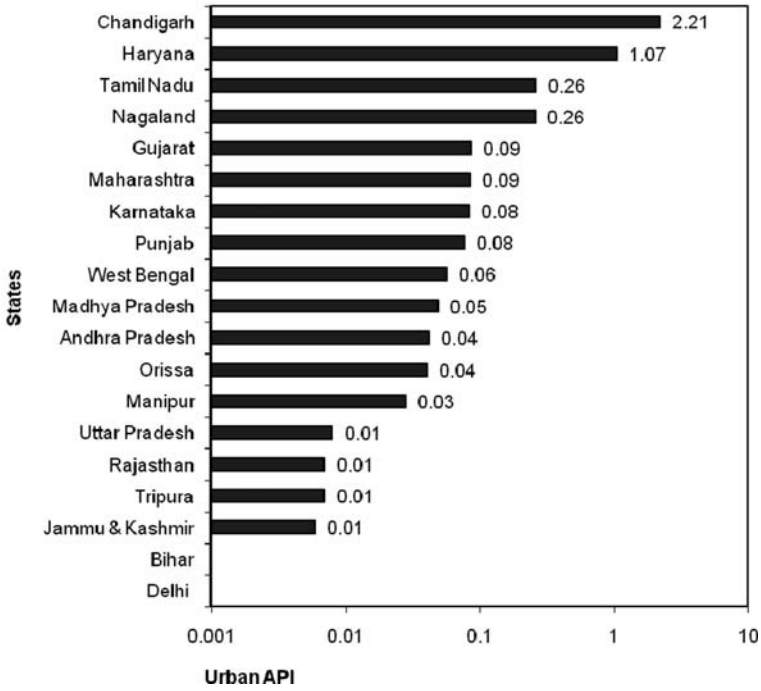


Fig. 9.2 Urban annual parasite index for selected states: India, 1997
Data source: NMEP[3].

Table 9.6 Proportion of *P. falciparum* cases to total positive cases and rate of change of proportion: Urban areas of selected states of India, 1994 and 1997

State	P.f. cases to total cases		State	Rate of Change 1994–1997
	1994	1997		
Jammu & Kashmir	0.00	0.00	Punjab	−100.00
Punjab	0.48	0.00	Delhi	−100.00
Delhi	0.65	0.54	Rajasthan	−98.92
Chandigarh	0.74	1.33	Haryana	−82.92
Andhra Pradesh	2.16	2.00	West Bengal	−79.13
Tamil Nadu	3.92	2.60	Gujarat	−73.23
Karnataka	5.85	3.02	Maharashtra	−46.34
Haryana	7.81	3.77	Karnataka	−34.61
Uttar Pradesh	10.31	3.83	Tamil Nadu	−23.04
Bihar	10.93	6.99	Manipur	−20.84
West Bengal	12.48	8.26	Uttar Pradesh	−19.90
Maharashtra	20.45	10.98	Orissa	−17.14
Gujarat	26.13	17.48	Madhya Pradesh	−10.06
Madhya Pradesh	32.61	29.33	Andhra Pradesh	−7.27
Nagaland	35.20	32.79	Nagaland	6.87
Tripura	39.78	37.50	Tripura	67.59
Manipur	41.42	37.61	Bihar	243.01
Rajasthan	49.73	66.67	Chandigarh	2256.53
Orissa	81.69	67.69	Jammu Kashmir	0 − 3.77
Mean	20.12	17.49	Mean Decline	−50.96

Data source: NMEP.[3]

Some Notes on Methodology

1. Since the only available urban malaria data were aggregated to the state level, we opted for a simple analysis that reflected general trends in spatio-temporal malaria occurrence that could be compared to the urban malaria scenarios presented in Chapter 8. For example, in Figs. 9.3, 9.4, 9.5, and 9.6, we chose to highlight only those states and Union Territories that presented with above-average levels of malaria intensity or *P. falciparum* infection for that year. This produced a fairly reliable picture of areas in India where urban malaria was more prevalent and which were thus likely to be foci of malaria occurrence for that time point.
2. Typically, the measure of centrality used for smaller samples with any degree of skewedness would be the median value. However, we used mean as a measure because it allowed for comparability with mean API values used in the study in Chapter 8 and removing the single outlier value resulted in a data distribution pattern amenable to the use of mean as a measure of centrality.
3. It was not possible to use a standardized number or unit against which the ‘high’ and ‘medium to low’ categories could be measured for all the time points in

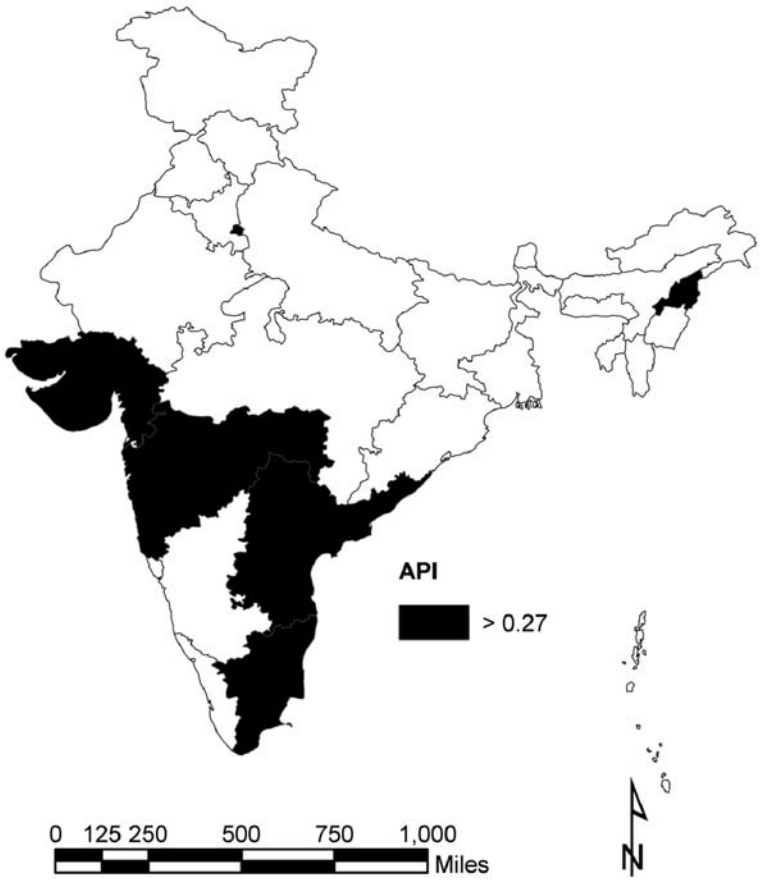


Fig. 9.3 States and union territories with above-average malaria incidence in 1994, India

Chapters 8 and 9 (i.e., 1978, 1993; 1994, 1997). The significant difference in mean APIs for each consecutive time point does not easily allow for such an exercise, particularly for the lower API values in the time points following 1978. It would entail calibrating categories to the point that they would not be particularly meaningful. Instead, noting states with above-average malaria intensity, and *P. falciparum* infection for a particular time point does allow for the tracking of areas that display higher rates than others at that same time point, thus providing a general picture of parts of the country that either resurface as centers of malaria occurrence time and again or might be emergent ones. We have also attempted to offset this difficulty of not having a standard number or unit to compare relative scenarios by using API change in both chapters, which facilitates an understanding of comparative spatio-temporal shifts in the malaria situation across the time points.

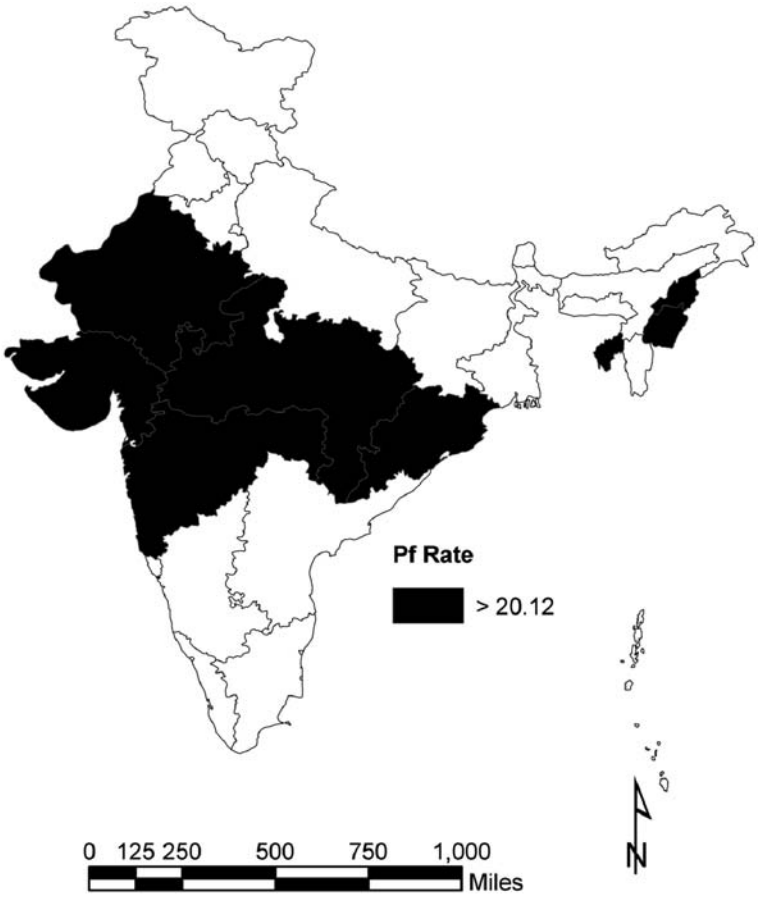


Fig. 9.4 States and union territories with above-average *P. falciparum* rates in 1994, India

Results and Discussion

Urban Malaria in 1994

Table 9.4 and Figs. 9.1 and 9.3 depict the intensity of urban malaria in India, as reflected in APIs of urban areas aggregated to state level for 1994. The southeastern states of Andhra Pradesh and Tamil Nadu, the western states of Maharashtra and Gujarat, the northeastern state of Nagaland, and the northern territories of Delhi and Chandigarh showed higher levels of malaria intensity as compared to the 1994 national average for urban areas (mean API was 0.27, excluding Chandigarh). This is strikingly similar to the pattern of urban malaria intensity in 1993 as given in Chapter 8.

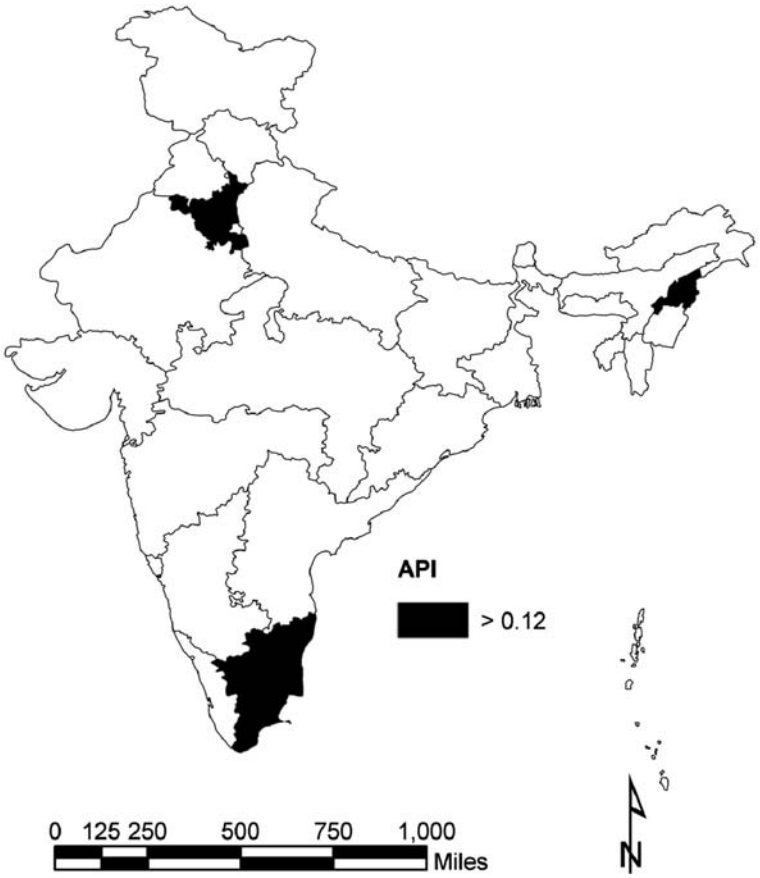


Fig. 9.5 States and union territories with above-average malaria incidence in 1997, India

The reasons for such a pattern are also similar to the ones cited in the previous chapter:

(a) The southern, western, and northeastern areas are endemic to malaria due to their climatic conditions, thus always prone to higher malaria intensities (Dutt et al. 1980).
(b) The resistance of the population to the disease had run its course of typically 8 to 12 years, rendering it malaria prone.
(c) The high APIs in Delhi and Chandigarh were possibly due to their urban nature, characterized by congestion, and slums with unhygienic conditions. These provide fertile breeding grounds for *Anopheles stephensi*, which is an important malaria vector in these urban areas (for a more detailed explanation, see Chapter 8).

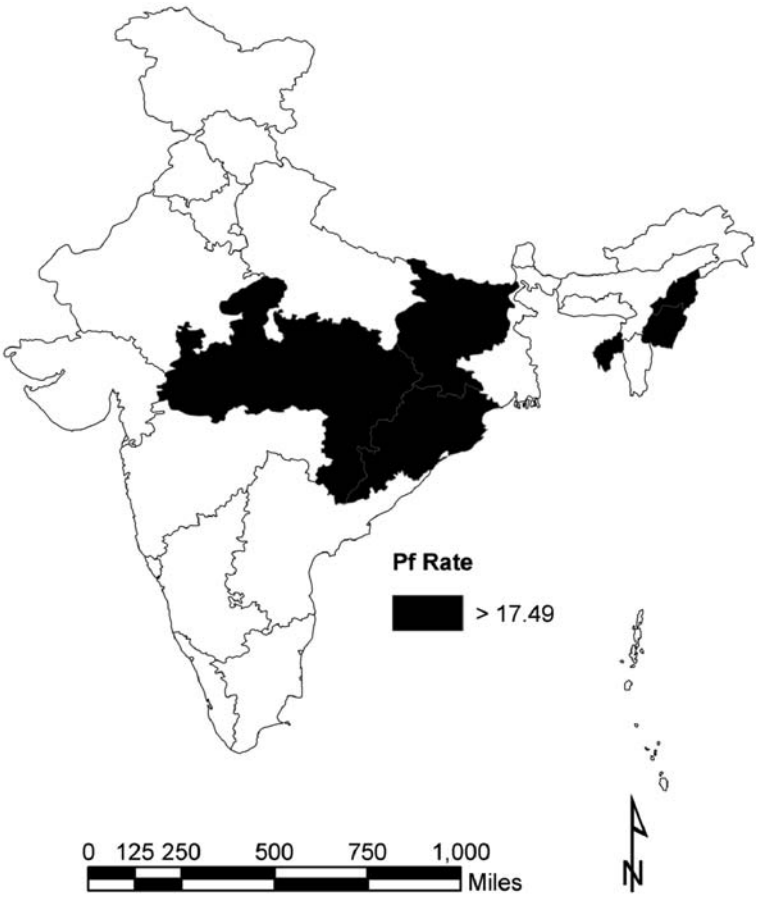


Fig. 9.6 States and union territories with above-average *P. falciparum* rates 1997, India

The proportion of *P. falciparum* cases to malaria positive cases (Table 9.6 and Fig. 9.4) are greatest in the eastern states of Nagaland, Tripura, Manipur, and Orissa, areas that are ecologically favorable to this *plasmodium*. The proportion of *P. falciparum* cases is also high in the western states of Maharashtra, Gujarat, and Rajasthan, as well as the contiguous central state of Madhya Pradesh, areas that have historically reported high numbers of *P. falciparum* cases (Akhtar and Learmonth 1986; Dutt et al. 1980).

Urban Malaria in 1997

Data for this year reveal an overall decline in malaria intensity (mean API of 0.12, excluding Chandigarh), which is lower than the 1994 mean API of 0.27 at a statistically significant level (two sample t-test: t. prob. $= 0.206$; $p < 0.005$).

Table 9.5 and Figs. 9.2 and 9.5 depict the distribution of urban malaria in India for the year 1997. Nagaland, Tamil Nadu, Haryana, and Chandigarh fall in the 'high' API category. Nagaland lies in the endemic northeast, and Tamil Nadu in the endemic south (Dutt et al. 1980; Dutta et al. 1979), explaining the relatively high API values. However, Haryana and Chandigarh far outstrip them in malaria intensity. This pattern is strikingly similar to the one presented for 1978 or the base year for the study in the previous chapter, albeit with lower intensity (API) levels. In 1978 API values showed high intensity of urban malaria in northern India, including Delhi, Haryana, Punjab, and Chandigarh, with relatively lower intensities in the south. Additionally, while the northern states of Punjab and Jammu and Kashmir do not figure in the 'high' category, they have shown a remarkable spurt in urban malaria that is also visible in Table 9.7 and Fig. 9.7.

The most probable reasons for the higher intensities in north India are as follows:

(a) The population resistance to malaria has possibly faded. Since almost two decades have passed since 1978 when malaria was highly prevalent in these areas, the second cycle of loss of resistance (each cycle lasts 8–10 years) would have set in.
(b) The urban areas of Chandigarh and the developing areas of Haryana still present an environment characterized by slums and construction areas that is conducive to the breeding of *A. stephensi*.

Table 9.7 Rate of change in urban API for selected states: India, 1994 to 1997

State	Rate of change (%)
Delhi	–99.99
Andhra Pradesh	–92.15
Rajasthan	–90.83
Tripura	–88.02
Bihar	–88.00
Manipur	–88.00
Gujarat	–86.81
Chandigarh	–79.80
West Bengal	–77.18
Tamil Nadu	–76.46
Maharashtra	–74.66
Orissa	–66.99
Madhya Pradesh	–65.62
Uttar Pradesh	–64.77
Nagaland	–13.72
Karnataka	–5.01
Punjab	32.81
Jammu & Kashmir	56.96
Haryana	413.67
Mean Decline	–72.37

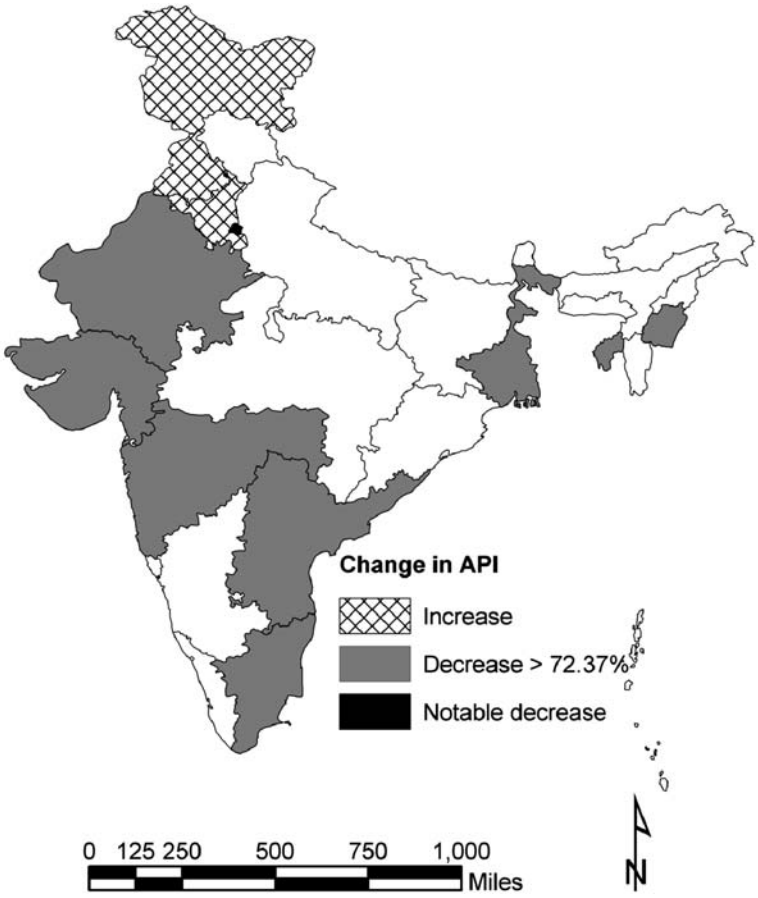


Fig. 9.7 Rate of change of malaria incidence 1994–1997 by states and union territories of India

Thus, the malarial intensity in urban India increases or decreases in a cyclical manner, based on resistance of the population to the disease and on the natural or human-made environmental suitability of the region to the breeding of the vector.

The proportion of *P. falciparum* cases to total positive cases (Table 9.6 and Fig. 9.6) still remained higher than average in the eastern states of Manipur, Nagaland, Tripura, and Orissa. It retained its 'high' status in Madhya Pradesh, which is contiguous to *falciparum*-endemic Orissa. Bihar joined this category, probably further influenced by Madhya Pradesh to its southwest. Madhya Pradesh and Bihar are also areas of historically high occurrence of *P. falciparum* cases (Dutt et al. 1980; also see Sharma 2003).

Shifts in Urban Malaria from 1994 to 1997

Although there was an overall decline in urban malaria in India from 1994 to 1997 (Tables 9.2 and 9.7), with the mean API dropping from 0.27 in 1994 to 0.12 in 1997, regional shifts in urban malaria during that time period varied from an actual increase to medium, low and sharp rates of decline (Fig. 9.7).

Areas reflecting an increase in malaria intensity were the northern states of Haryana, Jammu and Kashmir, and Punjab. The possible reasons for this have been mentioned in the sub-section above, namely the population's loss of resistance toward malaria, and the conducive vector-breeding environment found in the rapidly developing areas of Punjab and Haryana. The more established urban centers of these states are congested and provide many favorable conditions for *A. stephensi*. These conditions range from existence of slums or squatter housing, puddles in ill-maintained roads and other areas, construction areas with water collection sites, tanks, cisterns, and other features. Widespread waterlogging is a common feature during the monsoon season.

The emergent area of increase in urban API is the state of Jammu and Kashmir. Here, traditionally, it has been ecologically possible for the vectors to thrive and cause malarious conditions only in the valleys and low-lying areas. A possible reason for an increase in malaria occurrence here may be the flux of migrants to the developing areas of Punjab and Haryana in search of construction related and other jobs, and their return when such temporary work is over. These migrants may be bringing back the contagion to Jammu and Kashmir from the latter states. Another reason forwarded for this increase is related to the changing climatic conditions in the state: Akhtar (2007) points out that meteorological data for the region have shown sharp rises in temperature conditions and changes in mean rainfall, particularly in the last decade of the twentieth century. Looking at comparable data from around the globe, Akhtar (2007) warns that it is possible for such climatic changes to enable vectors and the *plasmodium* to thrive at higher altitudes than before, thus increasing the areal spread and magnitude of the disease.

All other states saw a sharp to medium–low decline. The average rate of decline was 72.37%. Among the states that experienced an above-average decline in APIs were the traditionally endemic areas of the south (Andhra Pradesh and Tamil Nadu), the west (Rajasthan, Gujarat, and Maharashtra), and the northeast (Tripura and Manipur), along with West Bengal in the east. This is commensurate with the 1978 scenario presented in Chapter 8, wherein the traditionally endemic areas have a lower incidence of urban malaria, possibly due to the increased resistance of the population toward the disease.

Two notable cases of sharp decline are Delhi (99.99%) and Chandigarh (79.80%). Both are administrative capitals with relatively large resources at their command that possibly facilitated requisite action for battling the disease. Anti-malarial activities intensify whenever malaria surfaces with greater severity and this in turn further diminishes new incidence of the disease in the following years.

P. falciparum rates for both 1994 and 1997 were high along a belt running from west to east through central India. This is consistent with findings in Akhtar and

Learmonth (1986, 1977) who noted that the *plasmodium* was responsible for a significant proportion of malaria cases in a belt across the middle of India, stretching from southeast Gujarat and northern Maharashtra in the west, Madhya Pradesh in central India, to Bihar and Orissa in the east. The *plasmodium* seems to avoid the plain areas of the north (Gangetic plain) and the plateau area of the south. The far eastern states of Tripura, Nagaland, and Manipur are forested tracts, as are most of Madhya Pradesh and Orissa, while the Kutch area of Gujarat has swampy characteristics. The *plasmodium* reflects a pattern of occurrence that reveals its propensity for these forested and swampy areas (also see Sharma 2003).

The rate of change in proportion of *P. falciparum* cases to the total (Table 9.6 and Fig. 9.8) revealed an increase in the eastern and northeastern states of Bihar, Nagaland, and Tripura, and the northern areas of Chandigarh and Jammu and

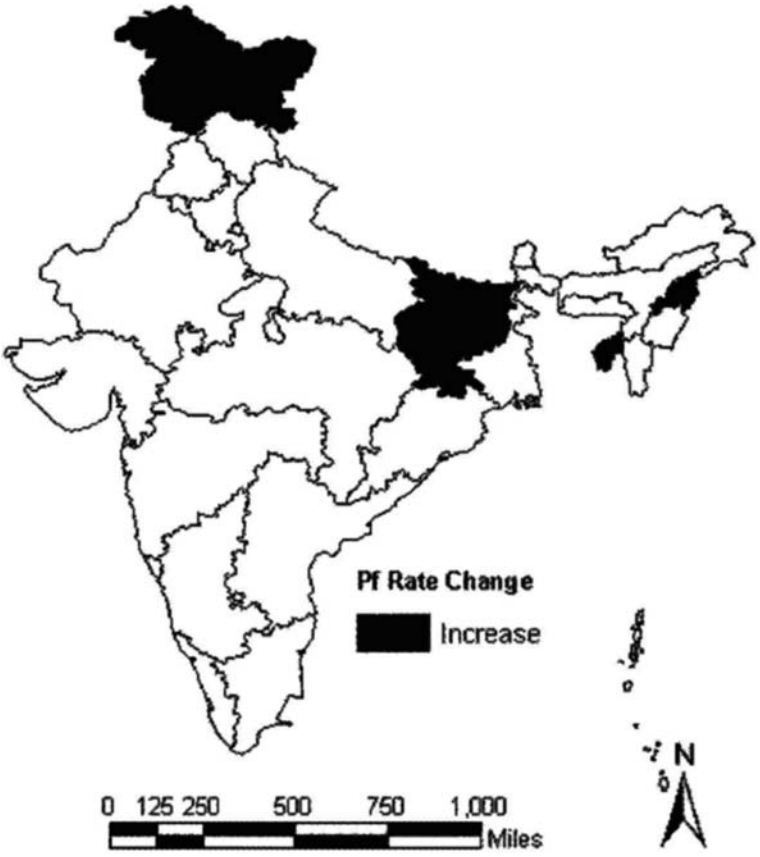


Fig. 9.8 Rate of change of *P. falciparum* proportion to total malaria incidence 1994–1997 by states and union territories of India

Kashmir. This signals a need for caution since Jammu and Kashmir and Bihar seem to be new areas with the potential for increase in rates of *P. falciparum* infection.

It is significant to note that in later years, along with the general decline of malaria cases and APIs during the 1996–2004 time span, *P. falciparum* cases have also declined from 1.18 million in 1996 to 1.05 million in 2000 and further to 0.84 million in 2004 (GOI 2006). This was a direct consequence of the government-led anti-malaria campaign. However, as discussed in the concluding section, the plasmodium is proving to be more than resilient against all efforts.

Dynamics of Urban Malaria in India, 1978–1997: Cycles of Resistance and Cycle of Regional Occurrence

The two phenomena that are most visible in the spatio-temporal occurrence of malaria are the 'cycle of resistance' and the 'cycle of regional occurrence,' which operate in conjunction with each other. The factors that have most determined such occurrence are (a) resistance of population to malaria, (b) endemicity of a region to malaria, (c) use or non-use of preventive and control measures against the disease, (d) developmental activities in the region, and (e) diffusion of malaria through population movement and the aspect of contiguous area diffusion.

The 19-year period (1978–1997) spanning the study in the previous and present chapters is marked by one complete 'cycle of regional occurrence,' which encapsulates within it roughly two 10-year 'cycles of resistance.' These two 'cycles' or phenomena are depicted in Fig. 9.9 and explained below, supported by relevant causative factors.

As mentioned earlier in this chapter, a population once affected by malaria remains resistant to the disease for an average of 8–12 years. In 1978, the population of the non-endemic northwest (Delhi, Haryana, Punjab, and Chandigarh) was not resistant to malaria, which was one of the factors responsible for the high rates of the disease, the other being the high levels of developmental activity that created environs suited to vector breeding. The population in the endemic south was more resistant at this point and consequently displayed lower intensities of malaria occurrence. However, some areas (such as in Tamil Nadu) still displayed relatively high rates of the disease due to the ever-conducive climatic conditions that promote the breeding of vectors and the spread of malaria.

The southern population would have begun to lose its resistance to malaria around 1990, reflected in the urban malaria pattern of 1993, where the southern part of the country had higher rates of malaria than the northwest. This elevated rate of malaria as compared to the northwest was also because the southeast (Tamil Nadu and Andhra Pradesh) and the west (Gujarat) are traditional centers of the disease due to their endemicity (see Chapter 8). At the same time, the northwest displayed lower malaria rates due to increased resistance, and greater preventive and curative measures focused on it by virtue of its administrative and economic importance. This ended one cycle of resistance and partially completed a cycle of regional occurrence.

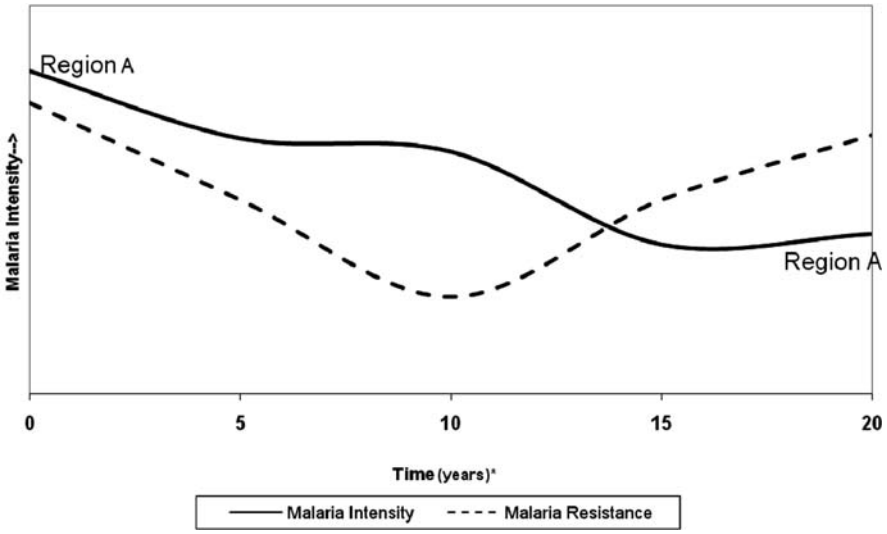


Fig. 9.9 Cyclical model of malaria intensity over time in urban India (depicting two cycles of resistance and one cycle of regional occurrence for hypothetical Region A: years 1–10 complete one cycle of resistance and 10–20 the other; the entire time span covers one cycle of malaria occurrence where it is high in years 1 and 20 *as compared to other regions*. Note that through the entire time span, malaria intensity continues to fall over time). *Assuming average malaria resistance cycle of 10 years

The year 1994 continued to reflect much the same pattern of malaria incidence as 1993, with higher rates of incidence in the endemic southeastern states of Tamil Nadu and Andhra Pradesh, the western states of Gujarat and Maharashtra, and the endemic northeast, and lower intensities in the northwest. However, by 1997, the northwest had lost resistance to malaria again (as in 1978), reverting to a malaria incidence pattern similar to that in 1978. The southern part of the country once again displayed lower rates of malaria than the northwest. The endemic areas of Tamil Nadu and Nagaland still had relatively high rates of malaria occurrence, but the northwest (Haryana and Chandigarh) displayed even higher rates. This concluded a second cycle of resistance and one complete cycle of regional occurrence.

The spatial scenario in 1997 had reverted back to the one in 1978, although the intensity of occurrence was much less than before. Therefore, we propose a cyclical model of malaria incidence in urban India (Fig. 9.9). Factors of regional diffusion and use/non-use of anti-malaria measures also affect malaria patterns over space, examples of which are highlighted here. In the northwestern part of the country, Haryana, Punjab, and Jammu and Kashmir have shown increases in malaria incidence. In the case of the latter, this may be due to workers coming in from this state for seasonal construction and development activity that was taking place in the former states, as well as climate changes. At the same time, Delhi reflected a steep decline, one of the major reasons for which is the extensive use of anti-malarial measures. In the southern part of the country, Tamil Nadu shows more elevated rates of

the disease even though contiguous states of Karnataka and Andhra Pradesh have shown declines. Apart from Tamil Nadu's endemicity as a result of warm climate with alternating wet and dry seasons, the other reason for the consistently high rate of malaria here was the lack of preventive and control measures used against the disease at the time, although these have now been stepped up.

Conclusion

From the above observations it is clear that malaria occurrence in urban India has been cyclic in nature. However, despite the apparent continuity of the malaria cycle, an encouraging trend that is noticeable is that each cycle and half-cycle has reflected overall falling intensities of malaria occurrence, with urban APIs declining from 11.51 in 1978 to 3.77 in 1993 to 0.27 in 1994, and finally to 0.12 in 1997.

However, past experience has shown that years in between might upset the trend—such as the epidemic in the mid-1980s and a rise of incidence to 3 million cases in 1996. Encouragingly, this has since reduced to 2 million in 2000 and more or less been maintained or reduced since then (GOI 2006; Sharma 1996; WHO/SEARO n.d.). The country as a whole has experienced a 40% decline in malaria cases during the 1996–2004 time period (GOI, 2006). In the years to come, care will have to be taken to keep this cycle of malaria intensity spiraling downwards, since there are additional threats such as climate change that could result in an increase in incidence and spatial extent. It has been shown that, for India, surface temperatures have increased over the past century or so, and rainfall patterns have shifted. It is highly likely that diseases such as malaria that are affected by ecological conditions will also shift patterns of intensity and areal occurrence, most probably in an adverse direction. Trend studies reveal that the disease will not only likely persist in currently endemic areas of the country but also gain a foothold in the currently non-endemic areas of southwest and north India (Akhtar 2007; Bhattacharya et al. 2006).

Other problems being faced in the battle against malaria is *plasmodium* resistance to the usual drug lineup including chloroquine and even to SP in some pockets, vector resistance to commonly used pesticides and the consequent change in vector behavior—i.e., they have become increasingly exophilic—lack of skilled human resources, funding shortages, and the rise in proportion of *P. falciparum* cases among others (see Sharma 1999, 2003). So far, the only means of interrupting this cycle seems to be preventive and control methods, since discussions in the previous chapters have shown that an effective vaccine may not be available for some time.

Some strategies being adopted by the Indian government are geared toward environmental methods of control of mosquito breeding including (a) breeding source reduction by filling ditches, pits, low-lying areas, (b) streamlining channels, desilting, deweeding, (c) better water disposal and sanitation, (d) emptying water tanks once in a week, and observing weekly dry days, and (e) anti-larval methods such as chemical and biological control through anti-parasitic aerosol sprays, and larvivorous fish, and biolarvicides. Other measures lay emphasis on reducing the reservoir

of infection by early case diagnosis and prompt treatment, adoption of ACTs in chloroquine and SP resistant areas, greater attention to urban settings since these areas have shown up to a 10% share of total malaria cases during 2003–2004 (Agrawal 2008; GOI 2004; NVBDCP n.d.; World Bank). Thus, for now, the best weapon in this constant battle seems to be that of proactive vigilance and prevention. In this exercise, EMCP's suggested strategies of better surveillance and epidemic monitoring, but even more so, community education and involvement regarding the nature of the disease and its prevention through personal protection measures such as ITNs (see Agrawal 2008) may well turn out to be most effective ways to keep malaria at bay.

Notes

1. This verse is a piece of popular poetry and familiar to Kolkata residents; it was suggested for inclusion by Rais Akhtar, recollected by Ashok Dutt and recorded by first author on April 28, 2000.
2. Sir Patrick Hehir (1859–1937) was a Major General in the Royal British Army who worked and wrote extensively on the malaria situation in India and proposed many public health measures to counteract its onslaught.
3. Data for urban malaria was provided by the NMEP. We are thankful to the Director, NMEP (now NVBDCP), Ministry of Health and Family welfare, New Delhi for providing access to the necessary data.
4. The above data for Jammu & Kashmir state include data for the Jammu region only as there was no comparable reporting by Kashmir and Ladakh regions of the state.

References

Agrawal, V.K. 2008. *Plasmodium Falciparum* containment strategy. *Medical Journal Armed Forces India*, 64(1): 57–60.

Akhtar, R. 2007. Health and climate in Kashmir. *Tiempo: A bulletin on climate and development*, 63: 19–21.

Akhtar, R. and Learmonth, A.T.A. 1977. The Resurgence of malaria in India 1965–1976. *Geojournal*, 1(5), 69–80.

Akhtar, R. and Learmonth, A.T.A. (eds.). 1986. *Geographical Aspects of Health and Disease in India*. New Delhi: Concept Publishing Company.

Bhattacharya, S., Sharma, C., Dhiman, R.C., and Mitra, A.P. 2006. Climate change and malaria in India, *Current Science*, 90(3): 369–375.

Dutt, A.K., Akhtar, R., and Dutta, H.M. 1980. Malaria in India with particular reference to two west-central states. *Social Science and Medicine*, 14D: 317–330.

Dutta, H.M., Dutt, A.K., and Vishnukumari, G. 1979. The resurgence of malaria in Tamil Nadu. *Social Science & Medicine*, 13D: 191–194.

GOI 1991. *Census of India: General Population Tables*. New Delhi: Office of the Registrar General & Census Commissioner.

GOI (1998) *Annual Report for the year 1997–98*. Delhi: Ministry of Health and Family Welfare. Now available at Ministry of Health and Family Welfare website at http://mohfw.nic.in/reports/1997–98Er/Part2Chapter4.pdf

GOI (2004). *Annual Report for the year 2003–04*. Retrieved June 10, 2009 from Ministry of Health and Family Welfare website http://mohfw.nic.in/reports/Annual2004/Annual%20Report%20Eng/CHAPTER-4%20.pdf

GOI 2006. *India 2006*. New Delhi: Ministry of Information and Broadcasting.
Hehir, P. 1927. *Malaria in India*. London: Oxford University Press.
NVBDCP n.d. '*Urban Malaria Scheme*'. Retrieved April 14, 2009 from Ministry of Health and Family Welfare website at http://nvbdcp.gov.in/UMS.html
Sharma, V.P. 1996. Re-emergence of Malaria in India. *Indian Journal of Medical Research*, 103(1): 26–45.
Sharma, V.P. 1999. Current scenario of malaria in India. *Parassitologia*, 41(1–3): 349–353.
Sharma, V.P. 2003. Malaria and poverty in India. *Current Science*, 84(4): 513–515.
Shiv Lal, Dhillon, G.P.S., Sonal, G.S., and Sita Rama Rao, B. 1998. *Country's Scenario of Malaria and its Control in India, March 1996*. New Delhi: N.M.E.P. Enhanced Malaria Control Project, Directorate General of Health Services.
WHO 2006. Malaria Vector Control and Personal Protection: WHO Technical Report Series 936. Retrieved June 17, 2007 from WHO website http://apps.who.int/malaria/docs/WHO-TRS-936s.pdf

Chapter 10
Lessons from the Past, View to the Future: Summary and Concluding Remarks

Vandana Wadhwa and Ashok K. Dutt

> *It is worth our time to suspend whatever ill feelings we may have for the mosquito and—for a moment—marvel at one of [hu]mankind's most tenacious tormentors. Indeed, it's in our best long-term interests to pay due respect to the mosquito as a formidable and potent adversary*
>
> Fitzpatrick (2006, p. 1)

Abstract South Asia is a cohesive region and yet diverse, both in terms of physical and socio-cultural environments. This concluding chapter summarizes these similarities and variations in the context of malaria occurrence and specifically highlights common challenges such as the ever-conducive climate and the threat of climate change, cultural practices, socio-economic constraints, and political disruptions. It updates the malaria situation in South Asia into the twenty-first century and discusses the successes and failures of new drugs like ACTs and the return to old mainstays like DDT. Also addressed are the changing directions of global programs, the value of regional and multi-sectoral approaches, and the promise held by technological and scientific advances. In the end, the best course of action for now seems to be the use of effective and sustained surveillance, prophylaxes, prevention, control, and cure measures.

Keywords South Asia · Physical and socio-cultural environments · Climate change · ACTs · DDT · Stockholm Convention on POPs · Malaria atlas project · Regional and multi-sectoral approaches · Malaria prophylaxes

Malaria has been one of the greatest scourges of humankind since millennia and continues to be a leading cause of mortality and morbidity even in this age of technological and medical advancement. According to the most recent World Malaria Report (WHO 2008), 109 countries are endemic for the disease and almost half the world's population is still at risk to malaria. While this report shows a downward

V. Wadhwa (✉)
Department of Geography and Environment, Boston University, Boston, MA, USA
e-mail: vandanaw@comcast.net

R. Akhtar et al. (eds.), *Malaria in South Asia*, Advances in Asian Human-Environmental Research 1, DOI 10.1007/978-90-481-3358-1_10,

trend in both clinical cases and deaths from the 300–500 million cases and more than a million deaths according to the last World Malaria Report of 2005, the reduction is due to better surveillance and counting methodologies rather than any decrease in malaria occurrence. Estimates vary, but malaria still kills almost a million people each year and causes debilitating symptoms in a quarter to third of a billion more (WHO 2008).

The war against this disease has been long and tireless, but malaria has continuously trumped the many and varied human efforts to eradicate this disease. Despite more than 100 years of attempts toward this end, there seems to be no sure-fire method of total eradication, although prevention and cure are now possible in many areas of the world (Akhtar, Dutt and Wadhwa 1998; also see Chapter 1). Malaria remains endemic to six of South Asia's seven countries, Maldives being the exception. The WHO sponsored global Malaria Eradication Program (MEP) undertaken in the mid-twentieth century had extremely encouraging results, with the disease all but eradicated from much of the region. However, the ensuing decades revealed that such eradication was a myth, with malaria resurgence a new and frustrating reality to contend with in this region. The primary reasons for such resurgence and the battle against it are summarized in the sections below.

Malaria Enablers: Physical and Cultural Environments

For centuries malaria has been endemic to South Asia; this remains the case even today. The physical environment of considerable rain followed by a few months of drought or less rain is part of the built-in monsoon climate that prevails in this realm. *Anopheles* breeds in these conditions if the temperature is warm enough for its multiplication, and the breeding and dispersal of malaria-carrying *Anopheles* mosquito has been an inevitable occurrence.

The second aspect of the habitat that merits consideration is the cultural environment. Human activity affects the spread or inhibition of malaria because the *Anopheles* mosquito needs a human host to infect, who in turn plays a part in furthering the infection, because when the *anopheles* bites an infected host, it then carries the host's infection forward by biting other humans. Therefore, the spread of malaria is facilitated by human activity that exposes them to mosquito bites. South Asian farmers often go to the fields for sowing, harvesting, and tending crops in their climatically suited light traditional garb that leaves them open to mosquito bites. Certain agricultural practices, such as the widespread growing of paddy rice, and nonmaintenance of irrigation canals often provide and expand breeding areas for the vectors.

Similarly, *Anopheles* mosquitoes in urban and rural areas invade the homes in particular hours of the night for their blood meal, and if they are carrying the malaria *Plasmodium*, infect the humans residing within (Dutta and Dutt 1978). Screening of homes and the use of mosquito nets whenever they have been affordable by the population are important preventive measures that have been very effective in preventing nocturnal mosquito bites. As mentioned in the introductory chapter, wire meshing was first put to use as window screens to keep out insects in the United

States in the 1860s and has been widely used since then; there is hardly an American home without window and door screens. This is not the case in South Asia, where only some bungalows that were resided in by those associated with the past colonial power have had them in the past (Dutta and Dutt 1978). While window and door screens have by now become a comparatively more common feature in middle, upper middle and upper class homes, a vast majority of the poorer populations living in urban areas as well as farmers and rural dwellers still cannot afford them, leaving them vulnerable to mosquito bites and malarial infections. Additionally, urban areas in this region have become new breeding grounds by simulating rural conditions in peri-urban areas. Urban slums with their unsanitary conditions have added to this problem. Paradoxically, development activities have also contributed to increasing vector-breeding areas, as pointed to in Chapter 8.

Within the socio-cultural milieu, the role of the economic-political environment cannot be discounted. This region is beset by problems on both these fronts: in the twentieth century, each of its member nations has seen its share of domestic and regional political turmoil that has often interrupted public health programs, and each has consistently chafed against the sheer lack of financial resources to divert toward the many challenges faced by newly independent economies. These challenges still present themselves to varying degrees today. Additionally, the circular relationship between malaria and its economic cost, and between poverty and malaria further disadvantages these nations and their peoples (Gallup and Sachs 2001; Sharma 1996a; for a comprehensive review see Khanum and Singh 2007).

Thus, the physical and socio-cultural environment for malaria breeding and spread was and continues to be favorable. As the preceding chapters have shown, the environment of the South Asian countries is such that despite human measures taken to curb the occurrence and spread of malaria, the disease has always been able to take hold in new ways and in new areas. It has constantly changed its characteristics from adaptations in breeding habits of the vector to development of resistance to standard curative measures by the *Plasmodium*—malaria has, to date, eluded the best of efforts toward eradication in this region. In fact, the very word "eradication" has become controversial, with international health and aid agencies preferring "elimination", showing their cognizance of the difficulty of the task at hand (Roberts and Enserink 2007).

Human Interventions Against Malaria in South Asia

The primary ways mosquitoes and malaria have been combated in South Asia have been by preventive and curative measures. In earlier chapters, DDT, Malathion, and other insecticide spraying have been described as preventive aspects of malaria control programs. Insecticide spraying has been useful in vector control through destruction of malaria-causing mosquitoes and inhibiting their breeding. Curative measures have involved the use of medicines such as quinine, which was used in the early years of the WHO sponsored MEP until synthetic anti-malarial drugs could be formulated. Drugs such as chloroquine and Sulfadoxine–Pyrimethamine (SP) were used in its stead for curative and prophylactic purposes and were extremely valuable to the MEP well into the latter part of the twentieth century.

However, the malaria *Plasmodium* has continuously stumped malaria control efforts by developing a resistance to these as well as many other combination and noncombination drugs. Malaria vectors in almost all countries of South Asia have also become resistant to pesticides such as DDT and BHC (benzene hexachloride, another organochloric insecticide) (World Health Organization/South East Asia Region Office [WHO/SEARO] n.d. a, 1, 2, 3, 5, 6). Almost all countries in the South Asian region have also displayed the post-resurgence characteristic of periodic fluctuations in malaria occurrence during the last quarter of the twentieth century, caused to some extent by *Plasmodium* resistance to these drugs and vector resistance to the pesticides.

Noting the potential hazards DDT poses to the environment as well as the human population, the chemical was banned from widespread use in the 1970s and is used in a restricted manner in most South Asian countries, primarily for limited spraying of residences and other buildings (WHO/SEARO n.d. a, 1–6). Lately, there has been some controversy on the topic as to the (social) cost/benefit aspect of DDT use, as was touched upon in the first chapter. DDT was banned from the industrialized nations by the 1970s, but they had already achieved eradication by then. Considering that malaria continues to ravage developing countries, further depleting their economic and human resources, WHO decided that the use of DDT in a regulated fashion should in fact be continued (see Chapter 1).

The Stockholm Convention on Persistent Organic Pollutants (POPs) that came into force in May 2004 allows for the use of DDT (and other similar chemicals as appropriate) for indoor residual spraying (IRS) for malaria vector control in accordance with WHO standards until equally effective and safer alternatives become available. The Convention puts into place control and monitoring mechanisms for its member nations, who are expected to report every 3 years on the progress in malaria control as well as in finding alternatives to DDT (UNEP 2005; WHO 2003; WHO 2006a).

It remains to be seen as to how many South Asian countries will adopt the tack of limited DDT use and whether it will prove as safe as it is effective. The fact remains that it is not only a cheap method, but has historically proven itself to be an efficient means of dealing with the malaria vector. Despite vector resistance to the chemical, it is still a very effective repellant and irritant, thus conferring protection from mosquito bites when sprayed in small doses on indoor walls. To that end, the WHO recommends an application of 2 g/m^2 of wall area twice a year (WHO 2005; Roberts and Andre 1994; Roberts, Manguin and Mouchet 2000).

Other prevention and public health measures such as use of larvicides and insecticide-treated bed nets have also been utilized in some South Asian countries and have met with some success. Larviciding is a very effective tool against malaria since it involves vector control at the very first stage of its development. Countries such as Maldives and India use biological and chemical larvicides, while others such as Sri Lanka and Bangladesh are attempting to stress upon their populations the importance of the use of bed nets, particularly long lasting insecticidal nets (LLINs) or insecticide-treated bed nets (ITNs) (WHO/SEARO n.d. a, 1, 3, 4, 6). However, despite some measure of success in these countries, these measures are relatively

much more expensive than more popular alternatives such as pesticide spraying, and the resource strapped countries of South Asia typically cannot implement these safer strategies on a larger scale to be truly effective. Even when funds become available from international aid agencies, these nations are hard pressed to find ways to create an efficient and comprehensive prevention coverage system.

In terms of treatment, given the phenomenon of vector resistance to singly administered malaria medicines, the best course of treatment is the use of Artemisinin-based pharmaceuticals in combination with other anti-malarial drugs, referred to as Artimisinin-based combination therapies or ACTs. ACTs have been shown to be effective in reducing symptoms and fighting the parasite within a very short time frame from time of administration—7 days if used singly and 3 days if used in combination with some other drugs (Arrow et al. 2004; WHO 2006b).

As mentioned in Chapter 1, the relatively new drug ASAQ is one such potent drug—a combination of artesunate and amodiaquine; it has the promise of performing triple duty as an effective, cheap treatment with a relatively simple dosing regimen that facilitates patient compliance (see Cheng 2007). However, underestimation of the malaria *Plasmodium*'s cleverness and of human carelessness can come at a heavy price. Areas along the Thai-Cambodian border in neighboring Southeast Asia are now beginning to show the deadly *Plasmodium falciparum's* resistance to ACTs. One of the causes for such a rapid onset of resistance is Artimisinin monotherapy since the lack of a combination of chemicals makes it easier for the parasite to develop resistance against any singly administered therapy. Artimisinin monotherapy is prevalent in the region since it is cheaper for the population than even the cheapest of ACTs—the WHO is attempting to work against this by not allowing such monotherapies on the market. Other reasons include counterfeit drugs and tainted drug formulations, and inappropriate or inadequate dosing and/or drug compliance (WHO 2009; McGivering 2009; Newton et al. 2008)

Malaria in South Asia: Nation-Wise Comparison and Summary

South Asia is a cohesive region in many ways; many aspects of physical and cultural environments are common to most of its nations. However, there are areas within this region that display divergent characteristics of not only the physical environment, but also the economic-political ethos, enough to create specialized conditions for malaria occurrence. For example, Sri Lanka is particularly environmentally prone to malaria occurrence, but can and has to a great extent beat the environmental givens through appropriate measures taken at the governmental level.

Climatically, Nepal's southern *Tarai* region is the most prone to malaria. This region also sees the greatest influx of migration from India and is therefore vulnerable to malaria diffusion through population movements. Bangladesh is currently affected by the malaria diffusion process emanating from its center and hilly regions that border India and Myanmar. In the case of Pakistan, large parts are too dry to

be endemic to malaria, but the irrigated and densely populated plains of Punjab and Sindh have become increasingly malaria prone. As in other South Asian countries, India's malaria incidence has declined dramatically since the 1950s, but during the post-resurgence period, different regions alternate to become new focal points of malaria diffusion. Moreover, as in Pakistan and India, urban malaria has become greatly aggravated.

Bhutan and Maldives, also part of South Asia, have not been discussed previously in this book. The latter was able to achieve malaria eradication by 1984 and has not seen any indigenous cases of the disease since then. This was achieved through vector eradication, operating in line with WHO Malaria Eradication campaign objectives. Early detection and immediate treatment continues to be an effective prevention and cure strategy (WHO/SEARO n.d., a, 4).

Bhutan's northern and central areas, which are primarily mountainous, are malaria-free, but the disease presents a significant public health risk in the areas that are forested and/or lie along the border with India. Bhutan was also engaged in the MEP and achieved eradication status that was maintained until about 1971, when the disease resurged and increased 100% by 1975 in the short span of 4 years. It remained more or less unchanged until 1981 then rose to its highest level ever in 1994. Since then, malaria continues to be present in temporally changing intensities, but mostly on a downward trend, probably as a result of the preventive and curative measures being taken. As with other countries of the region, drug and pesticide resistance of the vectors is a major problem, as is the dire lack of resources and infrastructure. (WHO/SEARO n.d. a, 2). However, the fact that Bhutan has a cooler climate than other South Asian countries greatly works to its advantage regarding the occurrence of malaria.

In the mid-twentieth century, South Asia was engaged in the Malaria Eradication Program sponsored by the WHO. All of its nations saw very encouraging results, with the disease all but eradicated by the 1960s, mainly through the implementation of vector control and drug prophylaxis measures. Despite the malaria-conducive physical and cultural environments prevalent in the South Asian nations, it seemed that the malaria occurrence had effectively been quashed. However, by the end of the 1960s and definitely by the 1970s, the disease resurged, not only in the traditionally endemic areas of the region, but also in new centers and foci, from where it diffused to previously less affected areas.

Much of this resurgence had to do with two factors: (a) vector and *Plasmodium* resistance to pesticides and drugs used in the Malaria Eradication Program and (b) the afore-mentioned economic-political ethos of these countries. The latter factor included aspects such as political turbulence in some of the nations that pulled resources away from public health and other social measures to defense spending, disruption of the MEP due to such turmoil, lack of political will that led to laid back attitudes and complacency among program planners and workers once goals seemed to have been met, and also the ever present lack of economic resources. All these occurred in various combinations and degrees, resulting in the varying spatio-temporal patterns of malaria resurgence experienced by the various nations comprising South Asia, as described in the preceding chapters of this book.

Malaria in South Asia in the Twenty-First Century: A Brief Update

In 2007, India had by far the highest mortality and morbidity rates, with almost 1.5 million reported cases and 1173 reported deaths. However, since many cases go unreported in this region, it is instructive to look at the estimated burden which was much higher. It was estimated that there were as many as 15,000 deaths and 10.6 million cases of malaria in India alone in 2006—an eye-opener to the significance of malaria monitoring and control in this entire region. Bangladesh was not far behind and suffered focalized epidemics in 2002, 2004, and 2005, with 6,600 mortalities and 2.9 million probable cases of malaria in 2006, which are high figures given its relatively smaller population. Pakistan had relatively lower mortality in 2006 (estimated at 1,400), but morbidity continued to be high, with almost 1.5 million estimated cases of malaria. These three countries ranked in the top 30 malaria endemic countries of the world, with India accounting for well over half the entire South Asian region's share of malaria incidence and mortality (WHO 2008; WHO/SEARO n.d. a, 1, 3).

Sri Lanka and Nepal showed the most promising progress in malaria control, not having reported any major epidemics. Although the disease continues to be present in these areas, Sri Lanka had zero deaths and relatively low morbidity of slightly under 600 reported and 3,300 estimated cases in 2006, with the situation continuing to show steady improvement. Nepal had higher morbidity with almost 31,000 cases, but fairly low mortality (30 cases). Bhutan also did not suffer any major outbreaks of malaria, being one of the only two countries in the region to have shown a significant reduction in malaria incidence from 2000 to 2006, with 20 deaths and 16,000 estimated cases of malaria in 2005 (WHO 2008; WHO/SEARO n.d. a, 2, 5, 6).

Given the malaria-prone environments of the above nations and the fact that *Plasmodium* drug resistance is a particular problem in this region, all South Asian countries continue to be vigilant against epidemics through surveillance and control practices, but the threat of malaria remains constant. Cognizant of this, some South Asian countries engaged in the Global Roll Back Malaria Initiative, a concerted effort sponsored by international organizations (WHO, World Bank, UNICEF, UNDP) and involving national governments, NGOs, private entities, donor agencies, and research organizations, to promote effective anti-malarial interventions primarily in the form of prevention and treatment (WHO/SEARO n.d. b). The efforts of the RBM and other technological efforts to combat malaria are discussed below.

Combating Malaria: A View to the Future

At various points in time, humans have tried to battle malaria in concerted efforts with differing goals depending on the prevalent knowledge and economic-political climate of the times: There was the WHO sponsored Malaria Eradication Program of the mid-1950s, which was replaced by the Malaria Control Program of 1992 when the realization sunk in that malaria could at best be controlled and contained rather

than eradicated. Today, the WHO continues to be the nodal agency that formulates and implements strategies regarding malaria control and research in partnership with other stakeholders. Some of these programmatic and research efforts are discussed below.

Roll Back Malaria Initiative (RBM) and the Global Malaria Program

By the end of the twentieth century, it became obvious to the WHO that malaria eradication could not be achieved by a one-time effort, but required continuous surveillance, vigilance, and action. It was also clear that malaria was a major player in the vicious cycle of ill health and poverty that was hobbling the socio-economic structures of many developing nations. Cognizant of these facts and of the lack of access to health and development resources, Dr. Gro Harlem Brundtland, then Director General of the WHO, spearheaded Roll Back Malaria (RBM) in 1998 (WHO/SEARO n.d. b). Obtaining the support of the member nations, agencies, and other stakeholders, this global partnership's mission is: "To work together to enable sustained delivery and use of the most effective prevention and treatment for those affected most by malaria by promoting increased investment in health systems and incorporation of malaria control into all relevant multisector activities" (WHO/RBM n.d. a).

RBM's goal was to reduce the malaria burden by half by the year 2010 and further reduce mortality by another 50% by 2015, while mindful of the vision of the Millennium Development Goals (MDGs) of halting and reversing malaria transmission by 2015. The major elements of the RBM strategy include (a) vector control and management through use of pesticides and ITNs, (b) case management through prompt diagnosis and appropriate treatment, including intermittent presumptive treatment, particularly during pregnancy, and (c) proactive monitoring and readiness in case of epidemics (Gardiner et al. 2005; WHO 2007).

However, in the first several years of RBM, malaria seems to be just as virulent and widespread as before, with some studies showing resurgence and increase in the disease in many countries, including some from South Asia (Attaran 2004; see Yamey 2004). In fact, in South Asia, the targets set for SEAR for the initial phase of the RBM spanning 2001–2006 to reduce malaria mortality and morbidity by 25% were not achieved, and while the situation in South Asia is not so dire as in Africa, even the countries of the subcontinent have seen malaria resurgence in unexpected areas and at unexpected times in the form of focalized epidemics despite overall declines in mortality and morbidity (WHO/SEARO n.d. c; WHO/SEARO n.d. d; WHO/SEARO 2005).

Although one of the key reasons for the persistence of malaria in this region has been drug resistance of *P. falciparum* (WHO 2006b; WHO/SEARO n.d. e; also see Wijayaratne et al. 2004), the failure to achieve targets here and in other parts of the world has led to criticism that RBM is not as effective as it should be,

either due to policy and management missteps, or due to technical problems on the ground (Attaran et al. 2006; Malaria Consortium 2002; WHO 2007). According to an evaluation of the program by the Malaria Consortium (2002, 2), some of the policy and management problems included "... inefficiencies in decision-making and ... lack of accountability; ... inadequate and sometimes inconsistent technical advice; [and] ... insufficient attention to multisectoral approaches to health sector development...".

One concern of RBM critics has been that the first problem arises with trying to measure progress in battling malaria—the Malaria Consortium (2002, 43) pointed out:

> No database exists for tracking global trends in malaria.... The main problem affecting RBM's data collection efforts, ... has been that an overly complex and insufficiently prescriptive approach has been taken. There has been a failure to clearly define goals and priorities of the M&E strategy at the global and regional levels, leading to confusion and *ad hoc.* data collection efforts at the country level. Too many indicators are proposed. Too many sources of data are suggested. ... Some countries are measuring one thing, some countries are measuring another.

Another major concern has been regarding the RBM tools used and their implementation—according to Bate (2006, 11):

> The primary culprits of RBM's failure are clearly its core players: USAID, WHO, UNICEF, World Bank among others. Their combined failure is typified in their perennial inability to employ, beyond a marginal scale, any of the most proven methods of malaria control. For instance, for many years, RBM failed to promote the use of IRS and the historically maligned but singularly effective insecticide, dichloro-diphenyl-trichloroethane (DDT). In addition, some donors, such as USAID, were reluctant and then sluggish to assist with the roll out of artemisinin-based combination therapy (ACT).

However, to give the WHO its due credit, it was not blind to its own faults. By its own admittance, the WHO acknowledged that the ambitious Roll Back Malaria initiative was falling short of its goals. Conflicts between the WHO Secretariat and that of the partnership agencies created more glitches in smooth operation of the program rather than smoothing the way for a seamless and comprehensive malaria prevention and control program (WHO 2007). This paved the way for launching the WHO-guided, more streamlined Global Malaria Program (GMP) that became operational in 2006. However, the RBM initiative has not been abandoned, but rather functions alongside the GMP, although the required restructuring and overhauling has been underway (Narain 2008; WHO 2007).

In South Asia, the concerns regarding RBM are many and coexist with other socio-economic and political challenges in the region. For instance, the RBM operates only in targeted districts of the region's nations, and not all these areas are able to actively following recommendations. This is mostly because they either are not in possession of the human and material/logistical resources whether in terms of adequate health systems, local surveillance structures, or appropriate networking from top levels to encourage community participation, or they face political disruptions, or both (WHO/SEARO n.d. f).

Nevertheless, in accordance with RBM and MDGs, the WHO (WHO/SEARO n.d. g) has laid down the following objectives for fighting malaria in Southeast Asia region (SEAR):

- Provide technical support and partnership networks to enable evidence-based strategies of malaria prevention and control
- Enable access to malaria treatment options to at-risk populations
- Create support networks to enable integrated vector management and other malaria control strategies
- Help strengthen malaria surveillance as well as its monitoring and evaluation at all scales of operation

The strategies laid down toward achieving these objectives are early case detection and prompt treatment (EDPT), integrated vector management, and containment of focal epidemics through early prediction and response (WHO/SEARO n.d. g). It should be noted that the drugs now recommended for malaria cure and prophylaxis are combinations of Artemisinin (WHO 2006b) since RBM had been roundly criticized for using cheaper drugs like chloroquine and SP in this region, where *Plasmodium* resistance to them is particularly high (see Bate 2006; Attaran et al. 2006). For prevention and protection, indoor residual spraying, larvivorous fish (in Maldives, India, and Sri Lanka) and ITNs have been adopted throughout the region in some combination or other. Bhutan and Bangladesh have seen particular success in lowering malaria incidence through the use of ITNs (WHO/SEARO n.d. a, 1, 2, 3, 4, 6); WHO 2008).

Efforts to develop more effective, safe, and cheap drugs and pesticides and strengthening health care structures continue across the globe through multi-sectoral partnerships such as the Medicines for Malaria Venture (MMV) and Multilateral Initiative on Malaria (MIM) (see WHO 1999). At this time, it seems these strategies of control and shrinkage of malaria occurrence and spread are the best course of action against a disease that has stumped eradication attempts again and again.

Malaria Vaccines and Other Advancements

Malaria control might be the best strategy at the moment, but the search for a more permanent measure such as an effective vaccine has not been abandoned. Several international private and public research and other groups have been working tirelessly in that direction, some prominent ones being the WHO Global Alliance for Vaccines and Immunizations (GAVI), European Malaria Vaccine Initiative (EMVI) founded in 1998 by the European Commission, Malaria Vaccine Initiative (MVI) established in 1999 by PATH, a Seattle-based health-oriented international nonprofit organization that received funds for this purpose from the Bill and Melinda Gates Foundation, National Institutes of Health (NIH, USA), USAID, Walter Reed Army Institute of Research (WRAIR, USA), University of Maryland Center for Vaccine

Development (UMd/CVD, USA), and many other pharmaceutical and academic research centers based all over the world.

Such is the urgency of finding a vaccine that between 70 and 100 different malaria vaccines are in various stages of development, several of them even competing projects sponsored by the same agency such as PATH's MVI. Only about 20–30 such vaccines have reached the trial phase of development (Gardiner et al. 2005; Finkel 2007; McNeil, Jr. 2007). Chapter 1 described some of the work in the field of vaccine development—the following continues that thread by reviewing some more of the major development in the area of malaria vaccines. A detailed clinical assessment of the various vaccine development efforts would be outside our purview, so a brief update is presented as applicable to the present scope of advances in vaccine development that could eventually contain malaria's huge social and economic costs in a significant manner.

Malaria vaccines usually tend to target one of the three stages of *Plasmodium*: the *sporozoite* stage (pre-erythrocytic), the blood stage (*merozoite* or asexual), or transmission stage (also known as "altruistic" vaccines since they do not protect the first host, but block parasite development in the mosquito and thus prevent malaria transmission to other potential hosts). The most researched vaccine type has been the pre-erythrocytic stage vaccine. As mentioned briefly in Chapter 1, one of the most promising of its type is the RTS,S vaccine first developed a little over two decades ago by GlaxoSmithKline Biologicals, which was put through clinical trials on semi-immune adults in Gambia in the 1990s. The vaccine did show safety and some degree of efficacy but results were not very encouraging due to the short span of protection conferred, and the vaccine was withdrawn from further testing in 1999 (Bojang et al. 2001; Los Angeles Times 2005).

However, GlaxoSmithKline continued vaccine development efforts through funding by the Bill and Melinda Gates Foundation, administered by PATH Malaria Vaccine Initiative. Dr. Pedro Alonso of the University of Barcelona in Spain was the lead researcher in these new trial and development efforts. In 2003, clinical trials were conducted on 2,022 Mozambican children aged 1–4 years, who were administered three doses of the vaccine. Alonso's findings appeared in the *Lancet*, showing that the vaccine was safe and effective enough to be a viable malaria vaccine, reducing malaria in general up to 35% and severe malaria up to 49%, conferring protection for at least 18 months (Alonso 2005).

Another effort in vaccine development that merits mention is one that revisits an older but rather encouraging method of evoking human immune response against malaria by introducing the attenuated malaria parasite, as was discussed in Chapter 1. Dr. Stephen Hoffman, CEO of Sanaria, Inc. based in Maryland, USA, is attempting to design a vaccine based on this technology (see Hoffman 2002). The set-back earlier had been the inability to introduce sufficient numbers of the parasites into the host to enable an adequate immune response—this challenge has now been overcome with newer technologies with which to create viable vaccine quantities—its success remains to be seen (Biello 2008; Finkel 2007).

Part of the problem with developing an effective malaria vaccine is that the *Plasmodium* constantly changes from stage to stage, and most vaccines are usually

designed to target only one of the stages. Also, the great degree of genetic variation in both the host and the pathogen poses a challenge to designing a vaccine that can address such diversity. Therefore, there are ongoing efforts to develop "cocktail vaccines" or combination vaccines that would be able to target the *Plasmodium* at all stages as well as factor in genetic variations, such as the "multi-stage, multiple-target" vaccine (FALVAC) being developed by the Centers for Disease Control (CDC) in Atlanta, Georgia (USA) (CDC, n.d.).

However, as mentioned in Chapter 1, even the most advanced vaccine candidate will not be licensed at least until 2010, since further testing for safety and efficacy will be required (BBC News 2004). As this work goes to press, the fulfillment of even this hope seems highly unlikely, and the current mainstays of malaria control will remain essential. As reported by BBC News (2004), Dr. Alonso said:

> It's difficult to imagine that we will have in the near future a magic bullet that by itself can sort out the problem of malaria, . . . Just like any other malaria control tool that we have, like insecticide treated nets . . . none of them is 100% effective . . . Control will rely on using a combination of malaria control tools together. . .[however] We believe a malaria vaccine, even of moderate efficacy, could make a huge impact.

Work on tackling the malaria problem on a radical (root) level is also in the works. The fact that the genomes of the vector and agent of malaria were decoded by 2002 has greatly increased the chances of developing a more effective vaccine, or even other strategies for malaria control, such as "genetic control" of vectors to enable desirable results such as sterility or greater resistance to the *Plasmodium* (see Gardiner et al. 2005, 507; McNiel, Jr 2007; Rinaldi 2004; also see Lambert and Siegrist 1997 for how DNA decoding helps in developing "intelligent" vaccines).

Some exciting new findings do promise hope: A study published in *Science* (Riehle et al. 2006) based on research led by Dr. Kenneth Vernick of University of Minnesota, St. Paul, in partnership with the Fred Hutchinson Cancer Research Center in Seattle, Princeton University and the University of Bamako in Mali explains the discovery that most malaria-carrying female *Anopheles* mosquitoes are resistant to or at least attempt to resist the *P. falciparum* as part of their genetic trait. In other words, the genetic makeup of these mosquitoes equips them to fight off the *Plasmodium* to a fairly significant degree. McNeil, Jr. (2006, A12) elaborates on this study to explain this phenomenon and its ramifications for the fight against malaria:

> Natural resistance in mosquitoes to the malaria parasite, *Plasmodium falciparum*, is good news for researchers because it is theoretically easier to bolster an existing gene than to implant one from another species. Also the [*Science*] study found that the resistance centers on a small section of one chromosome, rather than on many diverse sites, making gene manipulation easier.

However, since genetic manipulation can often be fraught with both difficulty and controversy, Dr. Vernick and colleagues suggest a new strategy: Instead of introducing new genes, or manipulating existing ones, aim for eliminating the few *Plasmodium*-susceptible alleles (gene components)[1] by using specific insect-devouring fungi that seem to preferentially target vectors that have the susceptibility allele. According to Vernick, the use of these fungi might eventually lead to

the complete eradication of the susceptivity genes, and thus perhaps halt malaria transmission (see Enserink 2005).

Meanwhile, the development of the "HapMap" a "database cataloguing of [human] genetic variation" is now being used in various ways, some of which may also advance the fight against malaria. Combined with a greater understanding of the *Plasmodium* genome, a number of aspects of better malaria control can be better tackled—for instance, the mutations the parasite undergoes as it attempts to resist anti-malarial drugs and immunogenic agents. With genome sequences of the host, vector, and the pathogen complete, there is hope that understanding the interactions among these will yield new ways to combat malaria (Couzin 2006, 1131; Gardiner et al. 2005).

Summary and Conclusion

South Asia displays a spatio-temporal pattern of malaria occurrence that is shared by most of its member nations. The disease has been universal throughout the region since the ages—this remains the case even today with the exception of the Maldives, which has not seen any indigenous cases since 1984. Preventive measures were adopted in all countries beginning in the 1950s with the introduction of WHO's Malaria Eradication Program; the most popular of these was DDT spraying. The result was an astounding drop in malaria occurrence over the next decade, leading to hopes of complete eradication of the disease in the region. Curative medicines were administered since the early decades of the twentieth century—chloroquine and its derivatives were still the most popular recourses in the latter half of the twentieth century, followed by some combination drugs in later years. These drugs proved extremely effective until widespread *Plasmodium* resistance was demonstrated in the last decade or so of the century.

Beginning in the 1960s and 1970s, resurgence of malaria episodes became highly noticeable, brought about by a number of factors common to the member nations. These included laxity on part of malaria control officers, economic stringencies, and political upheavals, and eventually, the phenomenon of vector and parasite resistance to the pesticides and drugs in use. This resurgence was then combated with newer drugs and insecticides, and presently, malaria occurrence displays constant fluctuations in spatio-temporal occurrence, which is characteristic of a post-resurgence phase. Currently, the hope of eradication lies in a combined strategy of treatment, prophylaxis, continued vigilance on part of malaria control officials and field workers, and scientific advancements as mentioned in the previous section.

However, like many other areas, some South Asian countries too now battle with the possibility that global warming brings the likelihood of tropical insects extending their habitat, thus bringing malaria to the doorstep of more temperate areas, both on the global and the regional scale. The effects of this phenomenon were presented in Chapter 1, and further review of studies illustrating the effects of even minor

climatic change on malaria occurrence has been conducted by Arrow et al. (2004, 231), wherein he points out the literature that supports evidence of increased malaria incidence even due to minor climatic changes in temperature and rainfall, or those wrought by the El Nino Oscillation.

With such commonality of malaria risk, incidence, and prevention characteristics, South Asia is united under one umbrella, and it needs a coordinated, comprehensive sustainable measure to combat the disease. The porosity of the national boundaries within the region also makes a regional approach not only desirable, but also mandatory. Some recent efforts elucidating a multi-sectoral and regional approach in Africa might provide valuable lessons; two such instructive events are recounted here.

In 1998, an international mining company, Billiton, began work on a large aluminum smelter 10 miles (about 17 km) from Maputo, capital of Mozambique. The operations faced extraordinarily high rates of absenteeism and fatalities caused by malaria. The mining company, in collaboration with the governments of Mozambique and the two adjacent countries of South Africa and Swaziland, launched a new effort in malaria control. This included the use and supply of "more powerful medicines, ... bed nets—the newest of which repel mosquitoes for five years, ... house-to-house indoor spraying, ... [and] targeted use of DDT, which remains controversial" (LaFraniere 2006, A9).

All these efforts took place on a regional scale and in cooperation with the governments of the three contiguous countries, since it was realized that malaria control would require a regional epidemiological strategy. Subsequent health surveys showed that (a) in targeted areas of South Africa and Swaziland, malaria incidence dropped from 66 cases per 1,000 persons in 1999 to only 5 cases per 1,000 in 2005 and (b) in southern Mozambique, 9 out of 10 children living in the area around the aluminum smelter were infected by malaria in 1999, but in June of 2005, the number fell to 2 in 10 (LaFraniere 2006, pA9).

The second such collaborative effort was initiated in 2003 on Bioko Island off the coast of Equatorial Guinea in the form of a Malaria Control Program funded by the Marathon Oil Company and in cooperation with the Government of Guinea. Malaria is endemic to Guinea and the discovery of oil and gas in the 1990s made it necessary for the efficient functioning of Marathon to embark on such a control program. The control strategy consisted of bet-net distribution, as well as "vector control through routine indoor residual spraying ... and an extensive program of case management and intermittent preventive treatment (IPT) for pregnant women..." (Kleinschmidt et al. 2006, p. 972).

Within 2 years, the initiative saw encouraging results since *P. falciparum* infection among children from 2 to <15 years of age reduced from 46% in 2004 to 31% in 2005. Like Mozambique, this project is "another example of a model" of a successful "private–public partnership" (Kleinschmidt et al. 2006). By 2008, further decreases in infections among children were seen, and the malaria-causing mosquitoes were drastically reduced—as a result, the program has been extended until 2013 to maintain and hopefully, build on these successes (Marathon 2008). These recent African experiences point to the fact that vigorous, innovative,

regional, and multi-sectoral efforts of malaria control are absolutely necessary and are extremely valuable in an endemic region with scant resources such as South Asia.

A descriptive model of scientific developments for assessing cause, remedy, and prevention of malaria is presented here within a historical perspective (Fig . 10.1). Sharma (1996b) also developed a model that posited that in the early 1950s, environmental factors determined the prevalence of malaria, while in the 1990s, the environment not only remained a factor in malaria occurrence, but that human interventions had not succeeded in the manner hoped. He explains that humans changed the ecology of entire regions in many situations providing more conducive scenarios for malaria occurrence. Their interventions in terms of pesticides and pharmacological agents fostered parasite and vector resistance. While Sharma's model is essentially a good explanation of the progression of events into the 1990s, it does not factor in the fact that even in the 1950s, the natural environment was not the only player in the malaria situation; medicines such as quinine and interventions such as public heath and sanitation measures were prevalent even before the 1950s. Drugs other than quinine had also become available in the 1940s, along with the pesticide DDT. Sanitation methods such as the use of oils for killing mosquito larvae, draining of stagnant water bodies, and clearing of excessive brush were practiced since the early years of the twentieth century.

We propose a more sophisticated and elaborate descriptive model using four variables: (a) time, (b) assumptions as well as empirical discoveries regarding causes

Chronology	Malaria Causes: Assumptions and Discoveries	Prevention, Cure and Eradication Efforts
Pre-19th Century	Understood as a **febrile illness** associated with "bad air" (*mal aria*), swamps and tanks. Concept of "miasmas"	**No known cure**, except in medicinal practices of Peruvian tribes (**bark of Cinchona-quinine**), and the Chinese (**Qinghao plant-artimisinin**). Use of Cinchona brought to the western world in the **17th Century** by returning Jesuits, then to the rest of the world by colonialists.
Mid to Turn of 19th Century	1880s-**Alphonse Laveran** identifies the malaria causing protozoon 1897-**Ronald Ross** confirms that the *Anopheles* mosquito is the malaria vector	Use of screens and mosquito nets becomes more popular. 1820-**Quinine isolated** from cinchona, used widely for treatment and prophylaxis
Early 20th Century	Scientific research identifies the four types of ***plasmodia* that cause malaria** (*P. falciparum, P. vivax, P. malariae*, *and P. ovale*), and the various species of ***Anopheles* mosquitoes** that carry and transmit these malaria-causing *plasmodia*. The optimal physical and human conditions for vector breeding and biting are also identified, as is the entire cycle of the malarial parasite.	Extensive **sanitation efforts**, **cleaning of swamps**, pools of water, **oil spraying** to kill mosquitoes. Contact with mosquitoes avoided in developed countries. Quinine used up to the 1930s, until anti-malarial **drugs are synthesized in the laboratory**.
Mid to Turn of 20th Century		**DDT** is first used in 1940s as an insecticide spray to kill mosquitoes. Other insecticides follow (BHC, HCH, **Malathion**). Intensive control efforts through WHO's **Malaria Eradication Program** begins in the 1950s; low cost, safe and effective, chloroquine is the drug of choice. Malaria eradicated in developed countries. False eradication in many developing countries. South Asia also experiences **false eradication**, then **resurgence** in late 60s and 70s, followed by **post-resurgence** fluctuations in malaria occurrence. Several new drugs are introduced. **Vector resistance to pesticides** and ***plasmodium* resistance to antimalarial drugs** is widely reported. **Search for an effective vaccine**.
End of 20th Century into 21st Century	**Genetic mapping** of *plasmodia*, vector and host complete, which can aid in the fight against malaria. Discovery of vector's natural resistance to the *plasmodium* and consequent possibility of reducing *Anopheles* presence through **genetic engineering** or use of naturally occurring insecticidal fungi	**Artemisinin** and artemisinin-combination drugs proving more effective than others in use despite looming resistance to these in some pockets of Southeast Asia. Restricted DDT use (IRS) permitted in vector control after much debate. **Search for a vaccine continues** (RTS,S/AS02A holds promise for children). Prevention, control and cure still first line of battle against malaria.

Fig. 10.1 Understanding malaria: a descriptive model of scientific progress

of malaria, (c) corresponding treatments and prophylaxes, and (d) scientific breakthroughs and their impact. This model depicts that while the pre-twentieth-century era seems like the dark ages in terms of understanding the workings of malaria, the late nineteenth century did bring two definitive scientific findings: (a) identification of the malaria *Plasmodium* as the agent of malaria and (b) association of malaria with the bite of the mosquito.

The hope remains that the twenty-first century is not only likely to see improvements in the quality and efficacy of anti-malarial drugs, but also the eradication of malaria from the face of the earth by (a) discovery and application of a potent vaccine, and/or (b) introduction of a genetic engineering technique to alter the *Plasmodium*-carrying capacity of the female *Anopheles*, and/or (c) vector destruction through innovative use of natural enemies of the *Plasmodium*-carrying Anopheles such as the insect-killing fungi. However, Rinaldi (2004) sums up the current malaria situation very cogently[2]:

> On the basis of current research, 'high-tech' molecular approaches to fight malaria will probably be possible within 10–20 years. These will be based on vaccines, mosquitoes genetically modified to be resistant to parasitic infection and transmission, and new anti-malarial drugs and insecticides. In the meantime, low-tech solutions are available ... We are at the crossroads. While researchers follow the path towards scientific advances for malaria control, the path leading to the political and financial implementation of existing effective measures is still in the shadows (last ¶).

In the midst of all the above "high technology" advances is a conceptually simple yet potent tool for enabling monitoring and evaluation of malaria spread and the efficacy of interventions against it. The Malaria Atlas Project (MAP) was started in 2005, mapping parasite prevalence based on medical and climate data. Thus far, only the prevalence of the deadly *P. falciparum* parasite has been comprehensively mapped, but the spatial spread of others, particularly *P. vivax* is now in the works. This will be a boost for anti-malarial activities in South Asia where this parasite is responsible for at least half of all malaria infections (Agrawal 2008; MAP n.d.).

The mapping of parasite occurrence is a reflection of malaria risk and broad swaths and pockets of South Asia too are classified as areas of intermediate and high transmission that require greater monitoring and intervention measures. Additionally, the greater population numbers and density in this area translate into greater risk for more people, thus sustained surveillance, control, prevention, and cure remain key policies. However, it is heartening to note that more of this region is now categorized as having lower endemicity than before, making malaria control and prevention a greater possibility (Hay et al. 2009; WHO 2008).

For Richer, for Poorer, in Sickness and in Health...

In early February, during a talk on malaria, entrepreneur and philanthropist Bill Gates released some mosquitoes into the crowd of the world's technology and entertainment elite attending the TEC (Technology, Entertainment, Design) 2009

conference, announcing: "There's no reason only poor people should have the experience." He also pointed out the irony that despite all the outlay for reigning in this killer disease, there was still more monetary investment into baldness drugs than went into malaria (The Seattle Times 2009).

Gates highlighted the fact that malaria occurrence was as much a function of poverty as of physical environment, a particularly relevant argument in the case of South Asia. Presenting a time-lapse map of global malaria occurrence since 1900, Gates showed how malaria had been eradicated from previously endemic areas of North America and Europe by the 1970s, mainly through the use of DDT. Tellingly, by the 1990s, the only other countries of the world that were able to eliminate malaria were ones commanding a high degree of monetary resources at their disposal, such as Australia. This same phenomenon was experienced in the twenty-first century by other emerging high-GNI nations such as Saudi Arabia. The map of 2009 malaria risk areas makes all too clear that it is the regions lacking these monetary resources that have been left to suffer the ravages of this disease, South Asia being one of them (see Bill & Melinda Gates Foundation 2009).

Add to this the scathing critique by some of the politics of malaria: The anti-malarial agenda is most often set by the above-mentioned resource-rich countries that have been able to get rid of malaria primarily due to the widespread use of DDT. Since they have experienced its detrimental environmental effects, they now seek to promote the use of safer but often costlier alternatives. However, discouraging the use of DDT through conditions on aid funds and other mechanisms might have been somewhat misguided as it has taken a heavy social and economic toll on developing nations that can ill afford such costs. For example, apart from human error and vector resistance, DDT's general fall from grace since the 1970s and a subsequent proposal for its global ban were partly responsible for malaria resurgence in some of the worst affected areas of the world as other more expensive and less effective insecticides were pressed into use. A similar case has been made regarding anti-malarial drugs, where cheaper drugs such as chloroquine and primaquine were still being used as first line treatment until a few years ago, even in areas of *P. falciparum* transmission, despite evidence of drug resistance (see Attaran et al. 2006; Bate 2006; Roberts et al. 2000; Tren 2002; Tren and Bate 2000; WHO 2006a; 2006b).

Often, the result of such nonparticipatory decision making leads to contextually inappropriate policies and guidelines that do not fully address ground realities. While the intentions of the major health and aid agencies are likely unquestionable, the above nexus between economic-political power and the direction of anti-malarial policies and the dichotomous power relations they breed make for a powerful set of arguments indeed. However, despite the stringency reflected in policy-molding exercises such as the Stockholm Convention, the present stance of the WHO regarding allowance of DDT use for indoor residual spraying and provision of free or subsidized ACTs as first line of treatment in *falciparum* malaria is a hopeful sign (WHO 2003; 2006b; 2008).

International agencies seem to recognize that financial and technical resources and know-how must not only be made readily available where needed, but also shared in a manner that allows for strengthening of the global south's own

infrastructure and anti-malarial network. One example is the international health community's emphasis on the significance of community participation in the control and reversal of malaria transmission through appropriate information, education, and communication (IEC) drives, particularly in regions such as South Asia, where awareness regarding causative and preventive mechanisms of malaria are still not adequate and impede anti-malarial activities (see Agrawal 2008).

Tren (2002) offers an interesting and insightful example of context-appropriate interventions. He provides the case of the use of ITNs and larvivorous fish in India: At times these measures have been misused since the population in such areas has used the fish as food source and the nets for fishing! Thus IEC and community participation is not a luxury, but a need. Likewise, the concept of "environmental sustainability" is often contextual: It might be more socially and therefore economically productive for populations of developing countries to use monitored and restricted amounts of a cheap and effective insecticide/irritant such as DDT than be constrained in its use and production.

Eventually, it is our hope that the discussions and analyses presented in the foregoing chapters provide a greater understanding of the nature of this resilient enemy and that South Asia's past experience offers insight what lessons to take away to effectively control and reverse malaria incidence in the region and globally, until more permanent measures are found. It seems highly likely that it will be up to the collective machinery of public and private research and administrative agencies to muster the political will and economic resources required to meet the great challenge of getting the better of this age-old disease.

As Notre Dame Biologist Nora Basansky (quoted in Fitzpatrick 2006, p. 4) so aptly puts it, "Maybe, . . . one day we can bite back."

Notes

1. One version of a particular gene. Each human cell has two copies of each gene. Those two copies are often different from each other because they have slightly different orders of genetic letters. Each copy is an allele: for example, one allele of the gene for eye color codes for blue eyes, while another allele codes for brown eyes. Retrieved May 15, 2009 from http://www.cgm.northwestern.edu/glossary.htm
2. The quote was directed to the situation in Africa, but is equally applicable to South Asia.

References

Agrawal, V.K. (2008), *Plasmodium falciparum* containment strategy. *Medical Journal Armed Forces India*, 64(1): 57–60.

Akhtar, R., Dutt, A.K. and Wadhwa, V. (1998), Health planning and the resurgence of malaria in urban India. In A. Noble, F. Costa, A.K. Dutt and R. Kent (eds.), *Regional Development and Planning for the 21st Century: New Priorities, New Philosophies*, Aldershot, England: Ashgate Publishing Ltd.

Alonso, P. et al. (2005), Duration of Protection with RTS,S/AS02A Malaria Vaccine in Prevention of *Plasmodium falciparum* Disease in Mozambican Children: Single-blind Extended Follow up of a Randomised Control Trial. *Lancet*, 366(9502): 2012–2018.

Arrow, K., Panosian, C.B. and Gelband, H. (eds) (2004), *Saving lives, buying time: Economics of malaria drugs in an age of resistance*, Committee on the Economics of Antimalarial Drugs, Board on Global Health, Washington DC: The National Academies Press. Retrieved June 5, 2006 from National Academies Press database.

Attaran, A. (2004), Malaria: Where did it all go wrong? *Nature*, 430(7002): 932–933.

Attaran, A. et al. (2006), The World Bank: False financial and statistical accounts and medical malpractice in malaria treatment. *Lancet*, 368(9531): 247–252.

Bate, R. (2006), para 11 USAID's *New Policy Reforms: Moving Past Rhetorical Comments to Real Changes*. Testimony, Senate Committee on Homeland Security and Government Affairs DC, Jan 19 2006, American Enterprise Institute for Public Policy Research. Retrieved March 3, 2008 from AEI website http://www.aei.org/publications/pubID.23703,filter.all/pub_detail.asp

BBC News (2004), '*Hopes of a malaria vaccine by 2010*,' BBC News, 15 October, 2004. Retrieved June 2, 2006 from BBC website http://news.bbc.co.uk/2/hi/health/3742876.stm

Biello, D. (2008), Self-Experimenters: Malaria Vaccine Maven Baits Irradiated Mosquitoes with His Own Arm. Scientific American, March 12, 2008. Retrieved April 8, 2008 from *Scientific American* website http://www.sciam.com/article.cfm?id=malaria-vaccine-researcher-lets-misquitos-bite-him

Bill & Melinda Gates Foundation (2009), *Bill Gates Speaks at the TED conference 2009*. Retrieved June 1, 2009 from Bill and Melinda Gates Foundation website http://www.gatesfoundation.org/speeches-commentary/Pages/bill-gates-ted-talk-2009.aspx

Bojang, K.A., Milligan, P.J.M., Pinder, M., Vigneron, L., Alloueche, A., et al. (2001), Efficacy of RTS,S/AS02 malaria vaccine against *Plasmodium falciparum* infection in semi-immune adult men in The Gambia: a randomised trial. *Lancet*, 358(9297): 1927–1934.

CDC n.d. *Vaccine development and evaluation*. Retrieved April 8, 2008 from CDC website http://www.cdc.gov/malaria/cdcactivities/research.htm#vaccine

Cheng, M. (2007), Malaria drugs could cut deaths in Africa, AP, March 1, 2007. Retrieved February 1, 2009 from *The Washington Post* websitehttp://www.washingtonpost.com/wp-dyn/content/ article/2007/03/01/AR2007030100173.html

Couzin, J. (2006), The HapMap Gold Rush: Researchers Mine a Rich Deposit. *Science*, 312(5777): 1131.

Dutta, H,M. and Dutt, A.K. (1978), Malaria ecology: A global perspective, *Social Science and Medicine*, 12(2): 69–84.

Enserink, M. (2005). Mosquito Killing Fungi may join the battle against Malaria. *Science*, 308(5728): 1531–1532. 514a DOI: 10.1126/science.312.5773.514a

Finkel, M. (2007), Bedlam in the blood: Malaria, *National Geographic*, July 2007: 31–67.

Fitzpatrick, M. (2006), Retrieved June 28, 2009 from http://www.nd.edu/~nbesansk/Pages%20from%20Pathways06_Screen.pdf

Gallup, J.L. and Sachs, J.D. (2001), The economic burden of malaria. *Am. J. Trop. Med. Hyg.*, 64(1,2)5:85–96.

Gardiner, D.L., McCarthy, J.S. and Trenholme, K.R. (2005), Malaria in the post-genomics era: light at the end of the tunnel or just another train? *Postgraduate Medical Journal*, 81: 505–509. Retrieved July 13, 2007 from PMJ Online Database

Hay, S.I. et al. (2009), A world malaria map: *Plasmodium falciparum* endemicity in 2007. *PLoS Medicine*, 6(6): e1000048. doi:10.1371/journal.pmed.1000048. Retrieved May 23, 2009, from Public Library of Science (PloS) database

Hoffman, S.L., Goh, L.M.L., Luke, T.C., Schneider, I. et al. (2002), Protection of humans against malaria by immunization with radiation attenuated *Plasmodium falciparum* sporozoites. *Journal of Infectious Diseases*, 185(8): 1155–1164.

Khanum, S. and Singh, A. (2007), Regional Health Forum, 11(1):33–44. Retrieved September 20, 2009, available at http://www.searo.who.int/LinkFiles/Regional_Health_Forum_Malaria_SEA_Region.pdf

Kleinschmidt, I. et al. (2006), Reduction in infection with *Plasmodium falciparum* one year after the introduction of malaria control interventions on Bioko Island, Equatorial Guinea. *American Journal of Tropical Medicine & Hygiene*, 74(6): 972–978.

LaFraniere, S. (2006), Business joins African effort to cut Malaria. *New York Times*, June 29: A9.

Lambert, P-H and Siegrist, C-A (1997), Science, medicine and the future: Vaccines and vaccination. *British Journal of Medicine*, 315(7122): 1595–1598. Retrieved April 8, 2008 from http://www.pubmedcentral.nih.gov/picrender.fcgi?artid=2127980&blobtype=pdf PubMed Central Online Database PMCID: PMC2127980

Los Angeles Times (2005), Malaria: The Sting of Death–The Hope of Vaccine (editorial), June 30 2005. Retrieved June 5, 2006 from *LA Times* website http://www.latimes.com/news/printedition/opinion/la-ed-malhope30jun30,1,4524626.story

Malaria Consortium (2002), *Achieving Impact: Roll Back Malaria in the Next Phase. External Evaluation of Roll Back Malaria*. Retrieved January 13, 2007 from WHO website http://www.rollbackmalaria.org/cmc_upload/0/000/015/905/ee_toc.htm

MAP n.d. Malaria Atlas Project Home page. Retrieved June 1, 2009 from MAP website http://www.map.ox.ac.uk/

Marathon (2008), Social Responsibility: Equatorial Guinea Malaria Control Project. *Marathon Facts*, retrieved June 23, 2009 from Marathon official website http://www.marathon.com/content/documents/fact_sheets/fact_sheet_malaria_june_2008.pdf

McGivering, J. (2009), Fears for new malaria drug resistance, *BBC News*, BBC World Service Cambodia, 28 May. Retrieved May 29, 2009, from the BBC World News website, http://news.bbc.co.uk/2/hi/asia-pacific/8072742.stm

McNeil Jr., D.G. (2006), Mosquito isn't a happy host for malaria, tests indicate, *The New York Times*, April 28, 2006: A12.

McNeil Jr., D.G. (2007), The Soul of a New Vaccine (corrections appended), *The New York Times*, December 11 2007. Retrieved March 3, 2008 from New York Times "Research" website http://www.nytimes.com/2007/12/11/health/research/11mala.html?_r=1&oref=slogin

Narain, J.P. (2008), Malaria in the South-East Asia Region: Myth & the reality. *Indian Journal of Medical Research*, 128(1): 1–3, Retrieved January 10, 2008 from WHO/SEARO website http://www.searo.who.int/LinkFiles/Malaria_editorial_Myth&reality.pdf

Newton, P. et al. (2008), A collaborative epidemiological investigation into the criminal fake artesunate trade in South East Asia. *PLoS Medicine*, 5(2): e32. doi:10.1371/journal.pmed.0050032. Retrieved June 23, 2009 from PLoS website http://www.plosmedicine.org/article/citationList.action;jsessionid=9149425C1656E1C4F36630E64E2AF4ED?articleURI=info%3Adoi%2F10.1371%2Fjournal.pmed.0050032

Riehle, M.M., Markianos, K., Niaré, O., Xu, J., Li, J., Touré, A.M. (2006), Natural malaria infection in anopheles gambiae is regulated by a single genomic control region. *Science*, 312(5773): 577–579. DOI: 10.1126/science.1124153

Rinaldi, A. (2004), Fighting malaria at the crossroads, *European Molecular Biology Organization Reports*, 5(9): 847–851. Retrieved April 9, 2008 from PubMed Central Online Database PMCID: PMC1299145 http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1299145.

Roberts, D.R. and Andre, R.G. (1994), Insecticide resistance issues in vector borne disease control. *The American Journal of Tropical Medicine and Hygiene*, 50(6 suppl): 21–34.

Roberts, D.R., Manguin, S. and Mouchet, J. (2000), DDT house spraying and re-emerging malaria. *Lancet*, 356(9226): 330–332.

Roberts, L. and Enserink, M. (2007). Did they really say...Eradication? *Science*, 318(5856): 1544–1545.

Sharma, V.P. (1996a). Malaria: cost to India and future trends. *Southeast Asian Journal of Topical Medicine and Public Health*, 27: 4–14.

Sharma, V.P. (1996b), Re-emergence of malaria in India. *India Journal of Medical Research*, 103: 26–45.

The Seattle Times (2009), *Bill Gates Unleashes Skeeters at Technology Conference*. Long Beach, CA: Associated Press, February 6, 2009. Retrieved May 29, 2009 from http://seattletimes.nwsource.com/html/nationworld/2008713678_apbillgatesmalaria.html?syndication=rss

Tren, R. (2002), *Malaria and Climate Change: Working Paper Series*, Julian Simon Center for Policy Research. Retrieved July 2, 2008 from http://www.libertyindia.org/pdfs/malaria_climatechange2002.pdf

Tren, R. and Bate, R. (2000), *When politics kills: malaria and the DDT story*. Retrieved May 27, 2009 from http://cei.org/PDFs/malaria.pdf

UNEP (2005), *Four new chemicals for phase out through stockholm convention*. UNEP, Punta del Este, Uruguay, 6 May 2005. Retrieved January 13, 2007 from UNEP News Center at http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=433&ArticleID=4788&l=en

WHO/RBM n.d a *What is the roll back malaria (RBM) partnership? 'Mission,'* Retrieved March 31, 2008 from WHO RBM website http://www.rbm.who.int/aboutus.html

WHO (1999), *Malaria Health Report 1999: Making a difference*. Retrieved April 5, 2005 from WHO website http://www.who.int/whr/1999/en/

WHO (2003), *WHO position on DDT use in disease vector control under the stockholm convention on persistent organic pollutants*. Retrieved January 13, 2007 from WHO website http://apps.who.int/malaria/docs/WHOpositiononDDT.pdf

WHO (2005), *Frequently asked questions on DDT use for disease vector control*. Retrieved January 17, 2007 from WHO website http://www.who.int/malaria/docs/FAQonDDT.pdf

WHO (2006a), *Indoor residual spraying: Use of indoor residual spraying for scaling up global malaria control and elimination*, World Health Organization Position Paper. Retrieved January 13, 2007, from WHO website http://malaria.who.int/docs/IRS-position.pdf

WHO (2006b), *Facts on ACTs (artimisinin based combination therapies*), RBM infosheet #9 (n.d.), updated January 2006, Sec I. last para, Retrieved June 10, 2006 from WHO website http://www.rbm.who.int/cmc_upload/0/000/015/364/RBMInfosheet_9.htm

WHO (2007), *Malaria, including proposal for establishment of World Malaria Day*. Report by the Secretariat: Sixtieth World Health Assembly, A60/12. Retrieved June 14, 2009 from WHO website http://apps.who.int/gb/ebwha/pdf_files/WHA60/A60_R18-en.pdf

WHO (2008), *World Malaria Report 2008*. Retrieved June 25, 2009 from WHO website http://apps.who.int/malaria/wmr2008/malaria2008.pdf

WHO (2009), *Drug resistance could set back malaria control success*. WHO News Release, 25 February 2009. Retrieved June 26, 2009 from WHO website http://www.who.int/mediacentre/news/releases/2009/malaria_drug_resistance_20090225/en/index.html

WHO/SEARO n.d. a *Malaria situation in SEAR countries*. Retrieved November 8, 2007 from WHO/SEARO websites (respectively)

1. Bangladesh: http://www.searo.who.int/en/Section10/Section21/Section340_4015.htm
2. Bhutan: http://www.searo.who.int/en/Section10/Section21/Section340_4017.htm
3. India: http://www.searo.who.int/en/Section10/Section21/Section340_4021.htm
4. Maldives: http://www.searo.who.int/en/Section10/Section21 / Section 340_4023
5. Nepal: http://www.searo.who.int/en/Section10/Section21/Section340.htm
6. Sri Lanka: http://www.searo.who.int/en/Section10/Section21/Section340_4026.htm

WHO/SEARO n.d. b. *Malaria: RBM—New initiative against malaria*, updated 20 April 2006. Retrieved April 1, 2008 from WHO/SEARO website http://www.searo.who.int/en/Section10/Section21/Section1368_9857.htm

WHO/SEARO n.d. c. *Review of roll-back malaria strategies in the south-east area region, Annex 2: Regional Strategic Plan (2002–2006)*. Retrieved April 1, 2008 from WHO/SEARO website http://www.searo.who.int/en/Section10/Section21/Section342_1071.htm

WHO/SEARO n.d. d. *Malaria epidemics/outbreaks in SEA region*. Retrieved April 1, 2008 from WHO/SEARO website http://www.searo.who.int/en/Section10/Section21/Section1987.htm)

WHO/SEARO n.d. e. *Malaria: Drug resistance*. Retrieved April 1, 2008 from WHO/SEARO website http://www.searo.who.int/EN/Section10/Section21/Section340_4039.htm

WHO/SEARO n.d. f. *Malaria: Issues and challenges*, WHOSEARO http://www.searo.who.int/en/Section10/Section21/Section336.htm Retrieved April 1, 2008 from WHO/SEARO website

WHO/SEARO n.d. g. *Malaria: RBM goals, objectives and strategies*, updated 20 April 2006. Retrieved April 1, 2008 from WHO/SEARO website http://www.searo.who.int/EN/Section10/Section21/Section335.htm

WHO/SEARO (2005), *RBM targets and achievements*. Retrieved April 1, 2008 from WHO/SEARO website http://www.searo.who.int/LinkFiles/Malaria_in_the_SEAR_RBMtargetSEARO.pdf

Wijeyaratne, P.M., Valecha, N., Joshi, A.B., Singh, D., and Pandey, S. (2004), *An inventory on malaria drug resistance in Bangladesh, Bhutan, India and Nepal*. Retrieved December 14, 2006 from USAID website http://pdf.usaid.gov/pdf_docs/PNACY099.pdf

Yamey, G. (2004), *Roll back malaria; A failing global health campaign* (editorial). *British Medical Journal*, 328(7448): 1086–1087. Retrieved April 1, 2008 from BMJ website http://www.bmj.com/cgi/reprint/328/7448/1086

Color Plates

Plate 1 Gangotri Glacier: Retreat of the mighty Gangotri glacier since 1780. The rapid melt and retreat has been primarily ascribed primarily to global warming. Continued melting will cause flooding of areas previously not prone to such conditions in the lower plains of the Gangetic valley, creating mosquito breeding areas where previously there were none or negligible. (Photo from Earth Observatory, NASA: http://earthobservatory.nasa.gov/IOTD/view.php?id=4594)

R. Akhtar et al. (eds.), *Malaria in South Asia*, Advances in Asian Human-Environmental Research 1, DOI 10.1007/978-90-481-3358-1,

Plate 2 *Anopheles Stephensi* killed by a fungus (in this case, *Beauveria bassiana*). The mosquito at the top has just had a blood meal, the middle mosquito was killed by the fungus 24 hours earlier and the bottom mosquito has been dead from fungal infection for 48 hours. Such fungi can act as viable biopesticides, as mentioned in "Malaria Vaccines and Other Advancements" in the concluding chapter. (Photo credit: Hugh Sturrock, Wellcome Images, http://medphoto.wellcome.ac.uk/)

Plate 3 Rubber tapping at a Hevea tree, Elston Estate. It is essential not to leave coconut halves in which the latex has been collected. The next rain will fill them up, turning them into breeding places for *Anopheles*. (Malaria in Sri Lanka. Photo by Gisela Peters and Wolfgang Peters, 1974.)

Plate 4 (**a**) and (**b**) Gem pit: In the Ratnapura area, gem pits are mined (**4b**), and excavated soil left in a heap (**4a**). In case a gem pit is left for a week or so, the *Anopheles* can breed in the water in the ground holes if the pit is not properly sheltered from the sun. Once the gem pit is completely deserted and digging for rubies has been given up, rain erodes the slopes, creating small holes with water that are visited by female *Anopheles.* (Malaria in Sri Lanka. Photo by Gisela Peters and Wolfgang Peters, 1974.)

Plate 5 Yala Park in the dry zone. Tank seen from the dam. High malaria risk dependent upon the water regime from season to season. (Malaria in Sri Lanka. Photo by Gisela Peters and Wolfgang Peters, 1974.)

Plate 6 A Chena farm in the Northeast monsoon area. (Malaria in Sri Lanka. Photo by Gisela Peters and Wolfgang Peters, 1974.)

Plate 7 River close to Talawakele. High malaria risk when drying out. (Malaria in Sri Lanka. Photo by Gisela Peters and Wolfgang Peters, 1974.)

Plate 8 Lake close to Nuwara Eliya, with Pidurutalagala, the highest mountain in Sri Lanka in the background. (Malaria in Sri Lanka. Photo by Gisela Peters and Wolfgang Peters, 1974.)

Plate 9 Tea estates close to Talawakele. Intensive tea culture as well as a lower temperature range help to prevent the spread of malaria. (Malaria in Sri Lanka. Photo by Gisela Peters and Wolfgang Peters, 1974.)

Plate 10 Peneplain, seen from Sigiriya Rock. Dry woods, tanks, and scattered small-holder farms are characteristic of the landscape. (Malaria in Sri Lanka. Photo by Gisela Peters and Wolfgang Peters, 1974.)

Plate 11 Mihintale Tank in the lowlands of the west and northwest with a high risk of malaria. (Malaria in Sri Lanka. Photo by Gisela Peters and Wolfgang Peters, 1974.)

Plate 12 Paddy fields at Kadduwa in the wet zone. (Malaria in Sri Lanka. Photo by Gisela Peters and Wolfgang Peters, 1974.)

Plate 13 Lagoon at Chilaw, west coast. (Malaria in Sri Lanka. Photo by Gisela Peters and Wolfgang Peters, 1974.)

Plate 14 Sorabora Wewa Tank in the east and northeast lowlands, following the Kundli-Manesar-Palwal (KMP) Highway from Kandy and Mahiyanganaya eastward. Scattered tanks reinforce the risk of malaria. (Malaria in Sri Lanka. Photo by Gisela Peters and Wolfgang Peters, 1977.)

Plate 15 Mahiyangana Tank. The area is subjected to the northeast monsoon, characterized by a greater rainfall variability. (Malaria in Sri Lanka. Photo by Gisela Peters and Wolfgang Peters, 1977.)

Plate 16 Yala Park. A romantic view, but nature has provided for a high malaria risk for humans. (Malaria in Sri Lanka. Photo by Wolfgang Peters, 1981.)

Plate 17 The Jamuna floodplain – relatively free of malaria due to annual/regular monsoon flooding and flushing of potential vector breeding areas. (Resurgence of Malaria in Bangladesh. Photo by K. Maudood Elahi.)

Plate 18 Chittagong hill tracts in Rangamati – the ideal malarial environment. (Resurgence of Malaria in Bangladesh. Photo by K. Maudood Elahi.)

Plate 19 Buckingham Canal on the east end of central Chennai Madras (formerly was built) during the colonial times for drainage purposes. Here, it seen stagnant and a breeding ground for mosquitoes. Slums and other houses are situated along the canal. (Malaria Resurgence in Urban India. Photo by A.K. Dutt, 1988.)

Plate 20 Slum housing in the northern part of Chennai with unsealed doors and windows, inviting mosquito invasion in the night. (Malaria Resurgence in Urban India. Photo by A.K. Dutt, 1988.)

Plate 21 A slum area in eastern Kolkata (formerly Calcutta) located beside the railroad tracks with a body of stagnant water where the slum dwellers washed their utensils. This water becomes a breeding ground for the mosquitoes after the rainy season. Also, slum doors and windows are not sealed, and malaria-causing mosquitoes have easy entry. (Malaria Resurgence in Urban India. Photo by A.K. Dutt, 1988.)

Plate 22 A slum colony in eastern Kolkata, made up of makeshift walls, situated right beside the body of stagnant water that invites mosquito breeding. (Malaria Resurgence in Urban India. Photo by A.K. Dutt, 1988.)

Plate 23 A slum in Bandra area of cultural Mumbai (formely Bombay), is located directly beside a stagnant water body. The water spreads into the slums during the rainy season, and during the non-monsoon months this water body becomes a breeding ground for mosquitoes. (Malaria Resurgence in Urban India. Photo by A.K. Dutt, 1988.)

Plate 24 Bhagalpur, a medium-sized town in the state of Bihar in eastern India, is in an endemic malaria zone. Here, the stagnant ponds are also used as drinking water sources for water buffalos and for cleaning household utensils. They are also breeding grounds for mosquitoes. (Malaria Resurgence in Urban India. Photo by A.K. Dutt, 1992.)

Plate 25 Madhubani, a small town in north Bihar, is also situated in the endemic malarial zone. Traditionally, the temple (this one being a *Kali* temple) has a tank or a pond of water used for ritual bathing purposes. These tanks usually do not have any outlets and provide breeding grounds for mosquitoes. Housing surrounds this temple and the tank, leaving the residents vulnerable to malaria. (Malaria Resurgence in Urban India. Photo by A.K. Dutt, 1995.)

Plate 26 Varanasi, a sacred Hindu city situated along the River Ganges in the State of Uttar Pradesh, is also in a malaria-infected zone. A stagnant water body surrounded by middle-class and upper-class housing and a slum is a perpetual breeding ground for mosquitoes. This water body is occasionally disinfected by the city's anti-malaria squads to prevent mosquito breeding. (Malaria Resurgence in Urban India. Photo by A.K. Dutt, 1992.)

Plate 27 A well-groomed lawn in the backyard of a two-star hotel in the city of Allahabad in the state of Uttar Pradesh. Malaria is quite prevalent in this area. Outwardly, it looks mosquito-free, but mosquitoes breed in the flowerpots and shrubs and in the small, stagnant pools of water on the rooftop. Though the rooms of this hotel are air-conditioned and the doors and windows are "sealed," mosquitoes enter the rooms when the doors are opened for service and through the tiny unsealed holes and restroom ventilators. Occasionally these rooms need to be sprayed with pesticides to keep them mosquito-free. (Malaria Resurgence in Urban India. Photo by A.K. Dutt, 2001.)

Plate 28 Open, unmaintained grounds in northwest Delhi. Water collects in such areas after the rain, but many of these pools and other ditches are left unfilled or untreated, presenting a potential mosquito breeding ground. (The Dynamics of Urban Malaria in India. Photo by Anubha Wadhwa.)

Plate 29 Many residences in India, like this apartment building in Delhi, use "coolers" to battle the summer heat. The coolers operate on a reservoir of water and can be fertile mosquito breeding grounds if not maintained regularly. (The Dynamics of Urban Malaria in India. Photo by Anubha Wadhwa.)

Plate 30 (**A**) and (**B**) A Delhi Municipal Corporation (MCD) employee treats the water in the coolers to prevent mosquito breeding. The chemicals used for such water treatments are water-soluble organophosphates in crystalline form, such as pirimiphos-methyl, used for exterminating larvae of *anopheles, culex*, and *aedes* mosquitoes. (The Dynamics of Urban Malaria in India. Photo by Anubha Wadhwa; information courtesy MCD, Wg. Cdr. J.L. Wadhwa, Swarn Bakshi-Wadhwa.)

Plate 31 An MCD-sponsored public health awareness poster, warning of the hazards of the mosquito, emphasizing prevention. (The Dynamics of Urban Malaria in India. Photo by Anubha Wadhwa; information courtesy MCD, Wg. Cdr. J.L. Wadhwa, Swarn Bakshi-Wadhwa.)

Plate 32 Killing spree: Salem Corporation workers spraying solution to control mosquitoes during Malaria and Mosquito Control Orientation Training program in Maravaneri, Tamil Nadu, India. (Photo: P. Goutham, The Hindu: Tamil Nadu. Online edition of India's National Newspaper, Aug 06, 2008. http://www.hindu.com/2008/08/06/stories/2008080650750300.htm)

Index