ELIMINATING MALARIA

Case-study 3

Progress towards elimination in Sri Lanka

UCSF GLOBAL HEALTH SCIENCES
THE GLOBAL HEALTH GROUP
From evidence to action

A.M.C.

World Health Organization

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TABLE OF CONTENTS

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The authors remain responsible for any errors and omissions.

ACRONYMS AND ABBREVIATIONS

ACD	Active case detection
ACT	Artemisinin-based combination therapy
AMC	Anti-Malaria Campaign
API	Annual parasite index
DDT	dichlorodiphenyltrichloroethane
G6PD	Glucose-6-phosphate dehydrogenase
IRS	indoor residual spraying
ITN	insecticide-treated net
LLIN	long-lasting insecticidalnet
PCD	Passive case detection
PCR	polymerase chain reaction
RDT	Rapid diagnostic test
WHO	World Health Organization

GLOSSARY

The terms listed in this glossary are defined according to their use in this publication. They may have different meanings in other contexts.

Active case detection

The detection by health workers of malaria infections at community and household level in population groups that are considered to be at high risk. Active case detection can be conducted as fever screening followed by parasitological examination of all febrile patients or as parasitological examination of the target population without prior fever screening.

Annual blood examination rate

The number of examinations of blood slides for malaria by microscopy per 100 population per year.

Annual parasite index

The number of reported malaria cases per 1 000 population at risk per year.

Case-based surveillance

Every case is reported and investigated immediately (and also included in the weekly reporting system).

Case definition (control programmes)

confirmed malaria

Suspected malaria case in which malaria parasites have been demonstrated in a patient's blood by microscopy or a rapid diagnostic test.

presumed malaria

Suspected malaria case with no diagnostic test to confirm malaria but nevertheless treated presumptively as malaria.

suspected malaria

Patient illness suspected by a health worker to be due to malaria. Fever is usually one of the criteria.

Case definition (elimination programmes)

autochthonous

A case locally acquired by mosquito-borne transmission, i.e. an indigenous or introduced case (also called "locally transmitted").

imported

A case the origin of which can be traced to a known malarious area outside the country in which it was diagnosed.

indigenous

Any case contracted locally (i.e. within national boundaries), without strong evidence of a direct link to an imported case. Indigenous cases include delayed first attacks of *Plasmodium vivax* malaria due to locally acquired parasites with a long incubation period.

induced

A case the origin of which can be traced to a blood transfusion or other form of parenteral inoculation but not to normal transmission by a mosquito.

introduced

A case contracted locally, with strong epidemiological evidence linking it directly to a known imported case (first generation from an imported case, i.e. the mosquito was infected from a case classified as imported).

locally transmitted

A case locally acquired by mosquito-borne transmission, i.e. an indigenous or introduced case (also called "autochthonous").

malaria

Any case in which, regardless of the presence or absence of clinical symptoms, malaria parasites have been confirmed by quality-controlled laboratory diagnosis.

Case investigation

Collection of information to allow classification of a malaria case by origin of infection, i.e. imported, introduced, indigenous or induced. Case investigation includes administration of a standardized questionnaire to a person in whom a malaria infection is diagnosed.

Case management

Diagnosis, treatment, clinical care and follow-up of malaria cases.

Case notification

Compulsory reporting of detected cases of malaria by all medical units and medical practitioners, to either the health department or the malaria elimination service (as laid down by law or regulation).

Certification of malaria-free status

Certification granted by WHO after it has been proved beyond reasonable doubt that the chain of local human malaria transmission by *Anopheles* mosquitoes has been fully interrupted in an entire country for at least 3 consecutive years.

Elimination

Reduction to zero of the incidence of infection by human malaria parasites in a defined geographical area as a result of deliberate efforts. Continued measures to prevent re-establishment of transmission are required.

Endemic

Applied to malaria when there is an ongoing, measurable incidence of cases and mosquito-borne transmission in an area over a succession of years.

Entomological inoculation rate

The number of infectious mosquito bites received per person per unit time.

Epidemic

Occurrence of cases in excess of the number expected in a given place and time.

Eradication

Permanent reduction to zero of the worldwide incidence of infection caused by human malaria parasites as a result of deliberate efforts. Intervention measures are no longer needed once eradication has been achieved.

Evaluation

Attempts to determine as systematically and objectively as possible the relevance, effectiveness and impact of activities in relation to their objectives.

Focus

A defined, circumscribed locality situated in a currently or former malarious area containing the continuous or intermittent epidemiological factors necessary for malaria transmission. Foci can be classified as endemic, residual active, residual non-active, cleared up, new potential, new active or pseudo.

Gametocyte

The sexual reproductive stage of the malaria parasite present in the host's red blood cells.

Hypnozoite

The dormant stage of the malaria parasite present in the host's liver cells (limited to infections with *P. vivax* and *P. ovale*).

Incubation period

The time between infection (by inoculation or otherwise) and the first appearance of clinical signs.

Intervention (public health)

Activity undertaken to prevent or reduce the occurrence of a health condition in a population. Examples of interventions for malaria control include the distribution of insecticide-treated mosquito nets, indoor residual spraying with insecticides, and the provision of effective antimalarial therapy for prevention or curative treatment of clinical malaria.

Local mosquito-borne malaria transmission

Occurrence of human malaria cases acquired in a given area through the bite of infected *Anopheles* mosquitoes.

Malaria-free

An area in which there is no continuing local mosquito-borne malaria transmission and the risk for acquiring malaria is limited to introduced cases only.

Malaria incidence

The number of newly diagnosed malaria cases during a specified time in a specified population.

Malaria prevalence

The number of malaria cases at any given time in a specified population, measured as positive laboratory test results.

Monitoring (of programmes)

Periodic review of the implementation of an activity, seeking to ensure that inputs, deliveries, work schedules, targeted outputs and other required actions are proceeding according to plan.

Parasite prevalence

Proportion of the population in whom *Plasmodium* infection is detected at a particular time by means of a diagnostic test (usually microscopy or a rapid diagnostic test).

Passive case detection

Detection of malaria cases among patients who, on their own initiative, go to a health post for treatment, usually for febrile disease.

Population at risk

Population living in a geographical area in which locally acquired malaria cases occurred in the current year and/or previous years.

Rapid diagnostic test

An antigen-based stick, cassette or card test for malaria in which a coloured line indicates that plasmodial antigens have been detected.

Rapid diagnostic test positivity rate

Proportion of positive results among all the rapid diagnostic tests performed.

Receptivity

Relative abundance of anopheline vectors and existence of other ecological and climatic factors favouring malaria transmission.

Re-establishment of transmission

Renewed presence of a constant measurable incidence of cases and mosquito-borne transmission in an area over a succession of years. An indication of the possible re-establishment of transmission would be the occurrence of three or more introduced and/or indigenous malaria infections in the same geographical focus, for two consecutive years for *P. falciparum* and for three consecutive years for *P. vivax*.

Relapse (clinical)

Renewed manifestation of an infection after temporary latency, arising from activation of hypnozoites (and therefore limited to infections with *P. vivax* and *P. ovale*).

Sensitivity (of a test)

Proportion of people with malaria infection (true positives) who have a positive test result.

Slide positivity rate

Proportion of microscopy slides found to be positive among the slides examined.

Specificity (of a test)

Proportion of people without malaria infection (true negatives) who have a negative test result.

Spleen rate

The prevalence of splenomegaly.

Surveillance (control programmes)

Ongoing, systematic collection, analysis and interpretation of disease-specific data for use in planning, implementing and evaluating public health practice.

Surveillance (elimination programmes)

That part of the programme designed for the identification, investigation and elimination of continuing transmission, the prevention and cure of infections, and the final substantiation of claimed elimination.

Transmission intensity

Rate at which people in a given area are inoculated with malaria parasites by mosquitoes. This is often expressed as the "annual entomological inoculation rate", which is the number of inoculations with malaria parasites received by one person in one year.

Transmission season

Period of the year during which mosquito-borne transmission of malaria infection usually takes place.

Vector control

Measures of any kind against malaria-transmitting mosquitoes intended to limit their ability to transmit the disease.

Vector efficiency

Ability of a mosquito species, in comparison with another species in a similar climatic environment, to transmit malaria in nature.

Vectorial capacity

Number of new infections that the population of a given vector would induce per case per day at a given place and time, assuming conditions of non-immunity. Factors affecting vectorial capacity include: the density of female anophelines relative to humans; their longevity, frequency of feeding and propensity to bite humans; and the length of the extrinsic cycle of the parasite.

Vigilance

A function of the public health service during a programme for prevention of reintroduction of transmission, consisting of watchfulness for any occurrence of malaria in an area in which it had not existed, or from which it had been eliminated, and application of the necessary measures against it.

Vulnerability

Either proximity to a malarious area or the frequency of influx of infected individuals or groups and/or infective anophelines.

SUMMARY

This report describes the policies and strategies used to control malaria in Sri Lanka from 1970 to 1999 and how malaria has been brought to the brink of elimination from 2000–2011. Lessons for countries that are pursuing or considering malaria elimination are distilled.

History of malaria and malaria control

Sri Lanka has a long history of malaria control, including a period of near-elimination and resurgence. Between 1947 and 1956, when indoor residual spraying (IRS) was initiated, the incidence declined from 413 to 0.35 cases per 1 000 people. The number of cases continued to decline until 1963, when only 17 cases were documented in the whole country. A major epidemic occurred 4 years later, however, and the number of cases reported reached 538 000 in 1969. Consequently, the programme reverted to a strategy of malaria control. Large numbers of cases were reported annually until 1999. Since that time the incidence of malaria in Sri Lanka has again decreased, from 264 549 cases in 1999, to 124 indigenous cases in 2011. Over this period, there has also been an increase in the proportion of cases due to *Plasmodium vivax* and in the proportion of cases among men.

Sri Lanka is attempting to eliminate malaria from its borders for the second time. While there are some similarities in the strategies and tools used in the two attempts, there are some major differences as well. The first elimination attempt relied heavily on IRS with DDT to reduce transmission, with the aim of national coverage. While IRS is still the primary means of vector control it is now targeted to high-risk populations only.

The choice of insecticides is also greater, allowing the rotation of several types and classes of insecticide, to reduce the risk of insecticide resistance, which impeded the first elimination attempt. New vector control tools are available today, which are useful for groups that are difficult to reach in IRS operations. The role of long-lasting insecticidal nets (LLINs) was particularly important during active conflict, as they gave populations 3 years of protection when IRS teams could not reach the area for months or even years. Entomological surveillance has been maintained, the results of which inform vector control strategies.

Sri Lanka has a strong passive case detection system. Active case detection was introduced in the late 1990s as a complementary strategy and has been scaled-up since 2003 in high-risk areas and for population groups that are hard to reach or have poor access to diagnosis and treatment. Investigations are conducted for each passively detected or actively detected case, including mass blood surveys to identify additional cases. Reporting of cases and deaths has been enhanced by instituting reporting within 24 hours, with measures to increase reporting from private clinics and physicians. Case review meetings, led by the Anti-Malaria Campaign (AMC) Directorate with regional malaria officers, allow feedback and discussion of best practices.

Both attempts at elimination, past and present, have included effective treatment of *P. falciparum* and *P. vivax* cases. Today, the new artemisinin-based combination therapies (ACTs) are used instead of chloroquine for treatment *P. falciparum* cases, combined with primaquine to eliminate gametocytes. Chloroquine for 3 days together with primaquine for 14 days continues to be used for the treatment of *P. vivax*, although adherence to the full regimen continues to be a challenge.

Lessons learned

The willingness and ability to quickly adopt new strategies according to new circumstances have contributed to the substantial decrease in cases seen since 1999. A strong emphasis on surveillance was maintained throughout, built on a solid health infrastructure and a focus on passive case detection. Importantly, malaria surveillance and control were maintained in the conflict districts, and the incidence dropped despite the civil war. Although in 1995 the incidence was similar in conflict and non-conflict districts, by 2000 the conflict districts accounted for the majority of infections, with an incidence of 71.5 per 1 000, while the incidence was 35.1 per 1 000 in non-conflict areas. The annual blood examination rate and the per capita rate of active case detection were higher in conflict areas. Although the estimated population protected by IRS in non-conflict districts was higher in 1995, by 2000 and 2005 coverage had been scaled up in conflict areas, despite serious risks for personnel, such as from landmines. LLINs were useful for protecting hard-to-reach populations, including those in conflict areas, and it is estimated that over a third of the population in conflict areas received LLINs.

Adequate funding over the past 15 years, from both the Sri Lankan Ministry of Health and external sources such as the Global Fund, made it possible for these strategies to be implemented nationwide. An assessment of programme expenditures in two districts indicated a 48% reduction in expenditure in Anuradhapura District, but a similar decrease was not observed in Kurunegala district.

Outlook for the future

Sri Lanka has set a goal of eliminating *P. falciparum* malaria by the end of 2012 and *P. vivax* malaria by the end of 2014. Early identification and treatment of infections, especially imported cases, and highly effective surveillance and response systems will be critical to achieving this goal. The risk of importation appears likely to increase: tourism revenues increased by 38% between 2009 and 2010, ferry services have resumed from Tamil Nadu, India, to Colombo, and smaller boat traffic between the countries is likely to increase in the coming years.

The current approach to elimination is based on strengthened surveillance, early reporting, case investigation and case management with radical cure. A mechanism for reporting malaria cases in the private sector is also being established. An information, education and communication programme targets at-risk populations. Other elimination strategies are also being developed or implemented, including border screening and treatment, formation of rapid response teams and a real-time malaria case information system.

The operational challenges of elimination and preventing reintroduction are numerous, not least the difficulty of maintaining adequate cadres and financial commitment when malaria is no longer seen as a priority. Without external support, pursuing elimination or strengthening the prevention of reintroduction may be difficult. If the momentum slows, there are historical precedents that a dangerous resurgence could swiftly follow.

INTRODUCTION

The malaria elimination case-study series

If countries are to make well-informed decisions on whether or how to pursue malaria elimination, an understanding of historical and current experiences of malaria elimination and prevention of reintroduction in other countries—particularly those in similar eco-epidemiological settings—is critical. The Global Malaria Programme of the World Health Organization (WHO/GMP) and the Global Health Group of the University of California, San Francisco—in collaboration with national malaria programmes and other partners and stakeholders—are jointly conducting a series of case-studies on elimination of malaria and prevention of reintroduction. The objective of this work is to build an evidence base to support intensification of malaria elimination as an important step in achieving international malaria targets.

Ten case-studies are being prepared that, together, will provide insights into and lessons to be learnt from a wide range of elimination approaches and geographical settings.

The University of California, San Francisco Global Health Group collaborated with Sri Lanka (formerly known as Ceylon) for the malaria elimination case-study reported here, because of Sri Lanka's history of elimination and, more importantly, because its recent progress towards elimination is not yet well documented. The main authors collaborated to collect data, including 3 months of in-country data collection, mainly on the past two decades of malaria control. The methods used for data collection and analysis for the case-study of Sri Lanka are summarized in Annex 1.

Malaria in the WHO South-East Asia Region

Tremendous progress has been made in the past 10 years in reducing morbidity and mortality caused by malaria *(1)*. Today, many countries are striving for malaria elimination—the interruption of transmission of all *Plasmodium* parasites within their borders *(2)*. This substantial progress was made possible by major improvements in global funding for malaria control and elimination during the past decade. The World Health Organization (WHO) South-East Asia Region is a good example of this trend: a marked decline in the number of confirmed cases has occurred in this Region, namely in Bhutan, the Democratic People's Republic of Korea, Nepal, Sri Lanka and Thailand. The number of cases in these countries fell by more than half between 2000 and 2010 *(3)*.

Malaria in Sri Lanka

The history of malaria in Sri Lanka has been turbulent. After the introduction of DDT (dichlorodiphenyltrichloroethane) in 1945 and near-elimination of malaria in the mid-1960s *(4–6)*, the island experienced a deadly resurgence of the disease, the number of cases shooting up to 1.5 million during 1967–1968 *(7)*. Major epidemics occurred in the 1980s and early 1990s *(4, 8)*.

During the past 12 years, the incidence again declined dramatically. This recent success is notable, not only because of Sri Lanka's elimination history but also in view of the major operational challenges posed by nearly 30 years of civil war between the Liberation Tigers of the Tamil Eelam (LTTE) and the Sri Lankan Government. Throughout the world, conflict has been shown to have negative consequences on the functioning of malaria control programmes *(9–12)*. Nevertheless, from 1999 onwards, Sri Lanka achieved major reductions in incidence

and is now considered to be in the pre-elimination phase *(3)*. Sri Lanka aims to interrupt the transmission of *P. falciparum* malaria by the end of 2012 and *P. vivax* by the end of 2014 *(4)*.

This case-study reflects the successful malaria programme of Sri Lanka and the factors that led to the sustained decrease in malaria incidence between 1999 and 2011. The epidemiology of malaria and the impacts of vector control, surveillance, case management, community engagement and education strategies are described. The efficacy of malaria control interventions in conflict and non-conflict districts are compared. An overview of expenditures on malaria control in two districts is presented, to show how the cost per capita at risk changed as the country moved from a highly endemic period towards elimination.

COUNTRY BACKGROUND

Geography, population and economy

Sri Lanka is an island in the Indian Ocean. Its closest neighbour is India, to the north-west, which is endemic for malaria. The total area of Sri Lanka is 65 610 km.^{2} The country consists mainly of low-to-flat plains, with mountains in the south-central interior with a maximum elevation of 2524 m *(13)*. It has three climatic zones: the south-west forms a wet zone, the north-west and western mountain slopes form an intermediate wet zone, and the north, east and south-east encompass a dry zone. In the past, malaria transmission occurred mainly in the dry zone and the intermediate wet zone.

The island experiences two main periods of rainfall, during two monsoon seasons. Malaria transmission is seasonal: the peak number of cases typically occurs at the end of the north-east monsoon season (December to March), with a smaller peak after the south-west monsoon (June to October). Storms and cyclones may affect the north-east coast from November to January.

Sri Lanka has a population of 20.3 million, with the majority living in rural areas (85%) *(14, 15)*. The major ethnic groups are Sinhalese (73.8%), Sri Lankan Moors (7.2%), Indian Tamil (4.6%) and Sri Lankan Tamil (3.9%), the remainder being other and unspecified, according to 2001 census data *(13)*.

Sri Lanka is a lower-middle income country *(15)*. The gross domestic product was US$ 59.2 billion in 2011, and the gross domestic product per capita was US$ 2375 in 2010 *(15)* (see also Annex 2). Agricultural land accounts for 41.6% of the total land mass, while 29.7% remains forested *(15)*. Sri Lanka's main agricultural products are rice, sugar-cane and grains. The main industries are rubber and tea processing, coconuts, tobacco and other agricultural commodities *(13)*. Tourism is becoming a major industry in the country, the number of international tourists having grown from 400 000 in 2000 to 654 000 in 2010, with a concurrent increase in tourism revenue, from US$ 388 million in 2000 to US$ 1 044 million in 2010 *(15)*.

The country is divided into nine provinces and 25 districts (Figure 1) *(16)*. Twenty districts are considered to be at risk for malaria.

Health system and population health profile

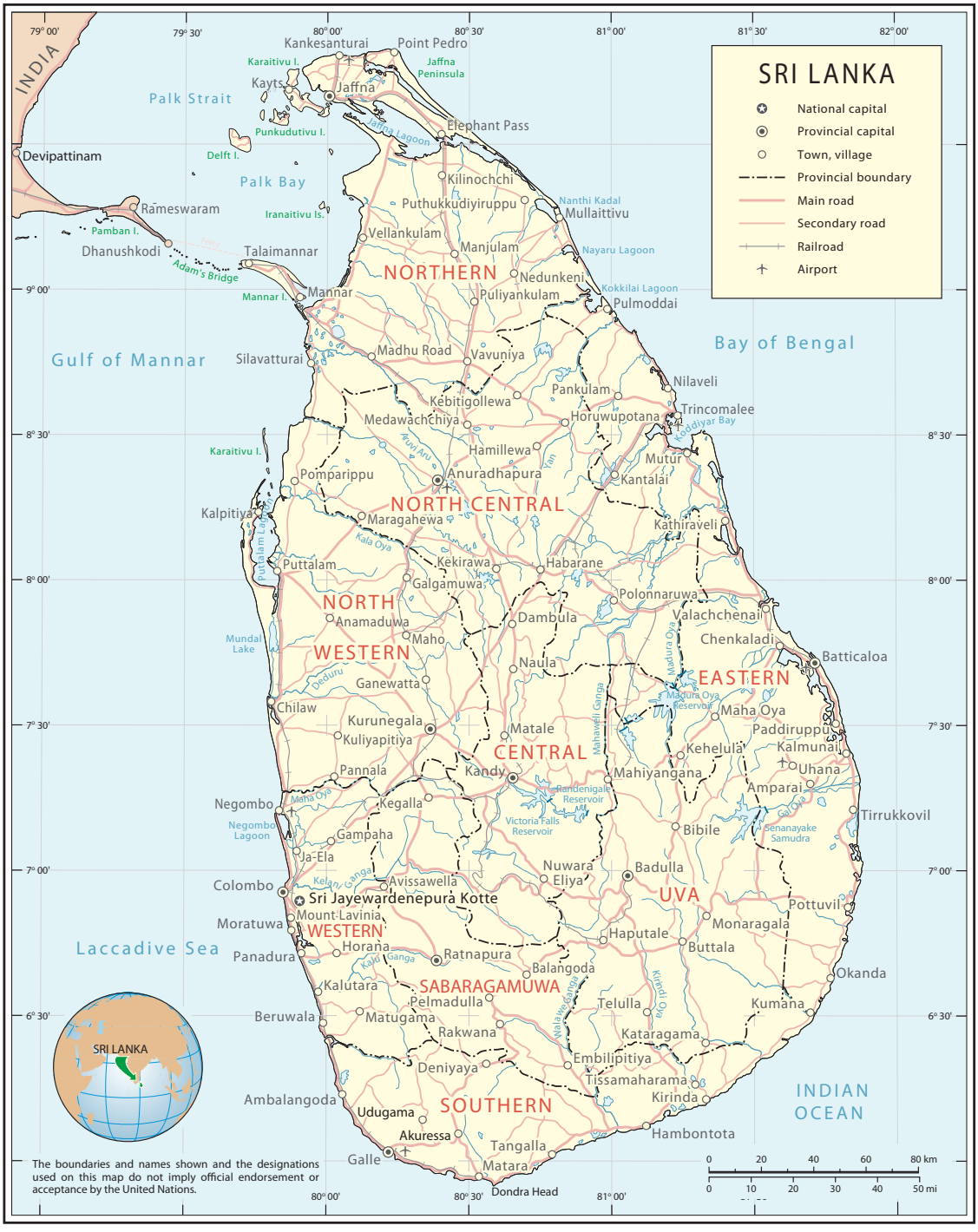
Since 1989 the health system of Sri Lanka has been decentralized. The Anti-Malaria Campaign (AMC), the national malaria control programme, is located in the Ministry of Health in Colombo. It formulates the national malaria control policy, monitors national malaria trends, provides technical guidance to subnational malaria control programmes, ensures inter-district coordination and coordinates training and research activities. The AMC also undertakes entomological and parasitological surveillance.

The 25 offices of the regional directors of health services manage district health services through the regional malaria offices, with one in nearly each district. Health area medical officers manage prevention and curative services at sub-district level.

Primary health care centres at district level refer patients to regional hospitals and ultimately to the national referral hospital in Colombo. In addition, many organizations participate in delivering and providing technical assistance to public health and infectious disease programmes

in Sri Lanka, including national and international nongovernmental organizations, research institutions, donors and funders.

Figure 1. Political map of Sri Lanka *(16)*



Map No. 4172 Rev.3 UNITED NATIONS
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Department of Field Support
Cartographic Section

Table 1 lists selected indicators of health service provision in Sri Lanka *(15)*. The country had 0.5 physicians per 1000 population in 2005–2010, whereas other low- and middle-income economies in the region had an average of 1.2 physicians per 1 000. The number of nurses and midwives per 1 000 was 1.9, while that in similar countries in the region was 1.5 per 1 000 *(17)*.

Table 1. Indicators of health care services in Sri Lanka

Indicator (per 1000 population)	Number	Year
Hospitals	Not available	Not available
Hospital beds	3	2004
Physicians	1	2004
Nurses	1.9	2005–2010

Annexes 2 and 3 show key demographic and health indicators. People aged 15–64 years account for 67% of the population; 25% of the population is in the age group 0–14 years, and 8% is 65 years and over *(15)*. The annual population growth rate was 1.1% between 2000 and 2010. Life expectancy at birth in 2010 was higher than in most other countries in the region: 75 years as compared with 72 years for lower- and middle-income countries *(17)*. Modeled estimates of maternal mortality ratios show a fall between 1990 and 2008 from 91 to 39 per 100 000 live births, while the estimate for the East Asia and Pacific region as a whole is 89 deaths per 100 000 live births *(17)*.

The country has a high rate of child immunization against measles (99%), which is higher than the average for upper- to middle-income countries (96%) *(17)*, indicating a robust infrastructure for health service delivery. Health expenditure represents 2.9% of the total gross domestic product in Sri Lanka *(15)*. Sri Lanka is ranked 97 out of 187 in the Human Development Index of the United Nations Development Programme *(18)*.

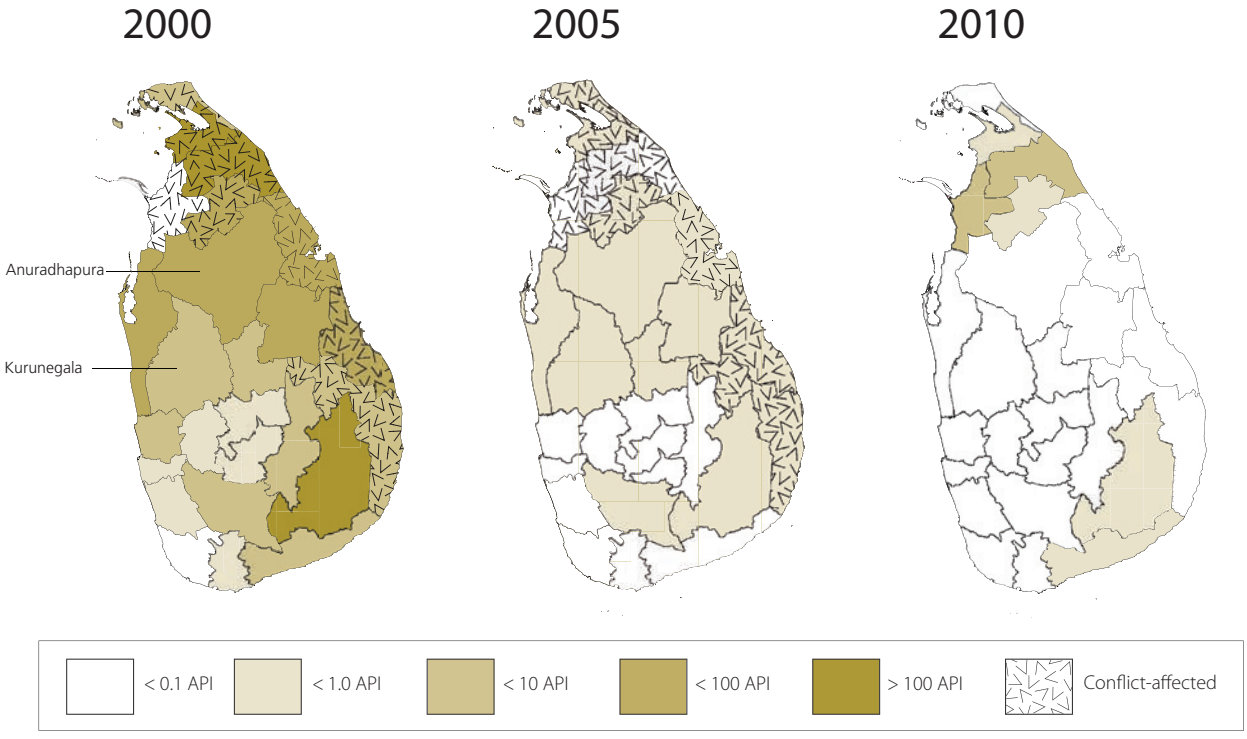
Conflict 1983–2009

Between 1983 and 2009, a conflict between Sri Lankan national forces and the separatist Liberation Tigers of the Tamil Eelam resulted in the internal displacement of people from the northern and eastern provinces and their border areas and strongly affected the provision of health services (see Figure 2). While the conflict affected the whole country its main effects were concentrated in eight districts, 5 districts in the Northern Province, and 3 districts in the Eastern Province *(19)*.

A ceasefire was declared in 2002, with a decrease in civilian casualties around this time, from 4000 in 2000 to 1000 in 2001, then 0 in 2002 and 2004 *(15)*. The ceasefire relinked the Jaffna Region in the north to the rest of Sri Lanka through regular commercial passenger flights and the reopening of route A9, a major artery for transport between Jaffna and Colombo *(19, 20)*. The peace agreement increased access to health services, food and other essential commodities in the northern and eastern districts, but the ceasefire was not respected by both sides at all times and violence continued to some degree *(19, 21)*. Therefore for the purposes of this case-study the eight districts were still considered to have been affected by the conflict during these years.

The ceasefire officially ended in 2006, when violence resumed in the north-east *(19)*. The eight districts are considered to have seen active conflict between 2005 and 2007, the number decreasing to six in 2008 and to four in 2009 (Figure 2). During this period, the annual number of deaths related to the conflict rose, peaking at 11 144 deaths in 2008 *(15)*. By May 2009, the war was declared over, and by December 2009, route A9 was again open. While access to the north of the island improved, there were still an estimated 460 000 internally displaced people in 2009 *(13)*.

Figure 2. Annual parasite incidence (API) by 1000 population at risk by district in Sri Lanka in 2000, 2005 and 2010
Only indigenous cases shown for 2010



HISTORY OF MALARIA AND MALARIA CONTROL

Parasites and vectors

Malaria in Sri Lanka has been primarily due to *P. vivax* and *P. falciparum*, with a minority of infections due to *P. malariae*, *P. ovale* and mixed infections. In recent years the proportion of cases due to *P. vivax* has increased as total number of cases has decreased. The principal vector of both *P. falciparum* and *P. vivax* in Sri Lanka is *Anopheles culicifacies* species E *(22, 23)*. Species E is found in a wide range of habitats, mainly at the edges of rivers in rock and sand pools, on agricultural sites and in wells and irrigation channels *(23)*. The vector is considered both endo- and exophagic (outdoor and indoor feeding behaviour), primarily endophilic (indoor resting), with a dusk-to-night biting time *(24, 25)*. The major secondary vector on the island is *An. subpictus*, of which two sibling species are present, A and B, associated with inland and coastal areas, respectively *(26)*. *An. subpictus* is found in coastal and brackish water, from small pools of water to rice fields *(25)*. This vector is also considered to be zoophilic; it is endophilic and bites at dusk or at night.

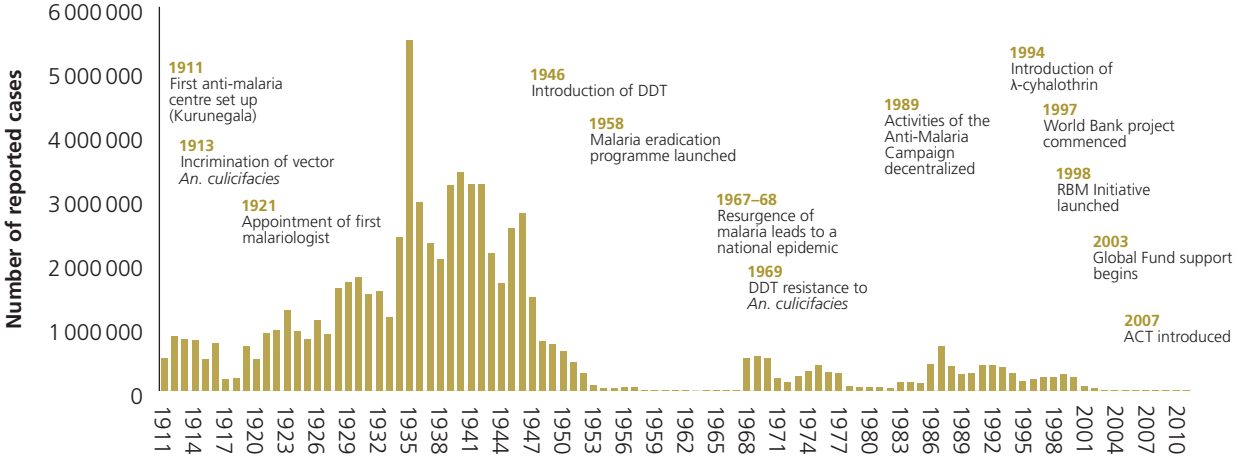
Pre-control

Researchers have noted the long history of malaria in Sri Lanka. Anuradhapura (Figure 1, 2), in the central region of the country and once the capital, was devastated by a 'pestilence' in 300 AD that was probably malaria *(27)*. Indigenous medical literature from 1300 AD onwards described a fever with symptoms similar to those of malaria, with a cycle of fever, anorexia, chills, rigors and other symptoms *(27)*. Records have been kept on malaria incidence and epidemics since 1906 *(27)*. Spleen surveys were carried out between 1908 and 1918 *(24)*.

Control (1921–1958)

From 1911 to 1920 Ceylon (as Sri Lanka was known during the colonial period) reported fewer than 1 million cases of malaria per year. Ceylon's first malariologist was appointed in 1921. Six years later, a 'special division' was created, with a sanitary engineer and a medical entomologist (Figure 3) *(27)*. Vector control at this time consisted mainly of anti-larval measures, such as oiling breeding

Figure 3. Timeline of incidence and major events in Sri Lanka's malaria programme, 1911–2011
IRS, indoor residual spraying; ACT, artemisinin-based combined therapies



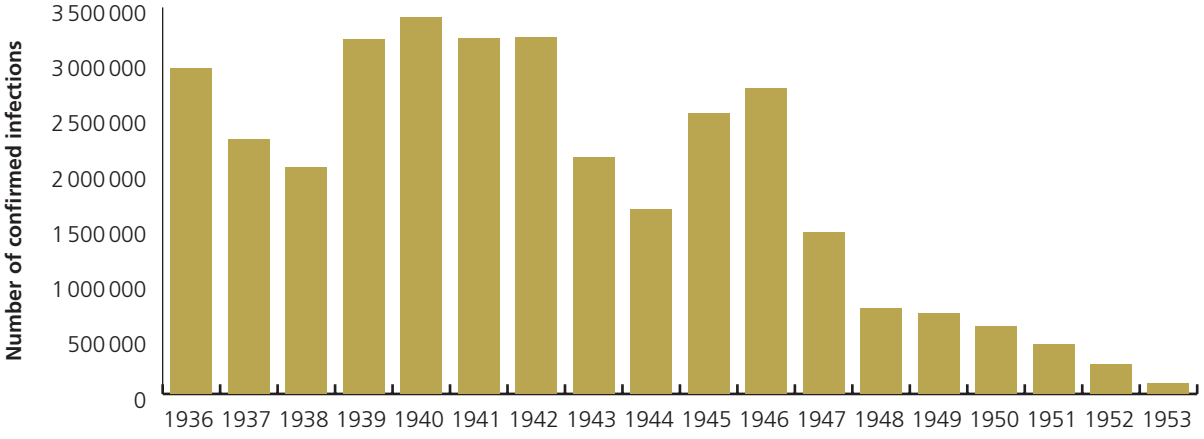
sites, spraying with Paris Green (copper(II) acetoarsenite), introduction of larvivorous fish and environmental engineering such as draining and filling *(27)*.

A major epidemic occurred on the island in 1935, reportedly affecting more than 3 million people and leading to at least 82 000 deaths (Figure 3) *(5, 28)*. The numbers of cases, spleen rates and numbers of deaths 1 year after the epidemic are shown in Table 2 *(29)*. Soon afterwards, control activities were extended, with use of pyrethrum insecticide sprays and suppressive drug therapy; entomological surveillance was begun, including observation of breeding sites to forecast seasonal epidemics, with collection of larvae and adult mosquitoes *(6)*. In 1940, this system was extended by requiring public health inspectors, operating as 'vigilance units,' to inspect rivers and streams for larvae in each jurisdiction *(6)*. Their observations were sent to a central malaria laboratory.

Ceylon reportedly was one of the first countries in Asia to implement indoor residual spraying (IRS), establishing the first mobile unit in November 1945 *(27)*. Once IRS was seen to be effective in 1946, it was extended to all malarious and potential malarial areas in the country, and all houses had been sprayed by the end of the year. Both DDT and benzene hexachloride were initially sprayed every 6 weeks, the interval later being lengthened to 3 months *(27)*. Entomological investigations continued to detect *An. culicifacies*, which was considered to be the only vector in Ceylon at that time *(27)*. By 1947, the island was protected for one full year *(6)*.

With the use of IRS, marked reductions were seen in the numbers of cases from 1947 onwards (Figure 4) *(6, 27)*, the incidence rate falling from 413 in 1946 to 0.35 in 1956. This result was attributed to use of DDT *(27)*. In 1953, the Minister of Health requested the services of a specialist in malaria eradication from WHO. Local experts did not believe that elimination was possible at that time, and WHO agreed, reporting that "elimination of malaria by species eradication was not feasible in this country"*(29)*.

Figure 4. Number of cases of malaria, Sri Lanka, 1936–1953



In 1955, the use of IRS was stopped in many regions, except where transmission was known to persist *(27)*. Active foci and gametocyte reservoirs were considered to remain throughout the dry zone because of the "habit of the people in these areas of cultivating inside the jungle in hidden clearings (and a) cultivation season coinciding with transmission season" *(6)*. At the same time, however, vigilance units were created to conduct monthly entomological surveillance, investigation of reported cases (with blood films) to determine the origin of infection and monthly visits to cleared transmission foci *(6)*. In addition, radical cure of positive cases was started in the 1950s, in which all patients received amodiaquine at doses of 600 mg, 400 mg and 400 mg on three successive

Table 2. Numbers of malaria cases, rates per 1000, spleen rates and numbers of deaths, 1936–1953

Year	No. of cases	Rate per 1000	Spleen rate (March surveys)	No. of deaths
1936	2 947 555	523	30.6	7 613
1937	2 308 976	404	–	4 408
1938	2 053 079	353	–	4 778
1939	3 210 795	544	18.2	10 039
1940	3 413 618	574	–	9 169
1941	3 220 360	535	18.4	7 132
1942	3 225 477	536	–	5 143
1943	2 141 329	349	–	6 765
1944	1 672 478	266	–	5 604
1945	2 539 949	391	–	8 539
1946	2 768 385	413	–	12 587
1947	1 459 880	212	10.3	4 562
1948	775 276	109	5.8	3 349
1949	727 769	100	2.7	2 403
1950	610 781	81	1.2	1 901
1951	448 100	58	0.8	1 599
1952	269 024	34	0.6	1 049
1953	91 990	11	0.3	722

days. Individuals with *P. falciparum* also received daily doses of 15 mg of primaquine for 5 days, and those with *P. vivax* received 15 mg of primaquine daily for 14 days *(6)*.

In 1956–1957, there was an outbreak of malaria in the dry zone, which was blamed on insufficient parasitological and entomological surveillance and the scattered foci of residual transmission in jungle areas among the populations who worked there. As a result, total coverage with spraying was reintroduced in all dry zone areas, along with strengthened surveillance *(30)*.

Initial efforts to eliminate malaria (1959–1969)

In 1959, a malaria eradication strategy was prepared, consisting of short-term, intensive IRS, passive case detection (PCD) and treatment *(27)*. By 1963, only 17 cases were documented, of which 11 were imported *(5)*. The country became one of the first to adopt the WHO reporting system on surveillance operations, and WHO found the quality of reporting to be satisfactory, with "efficient operation and supervision of the programme." PCD was considered to be efficient in capturing cases *(30)*. Because of this success, the country entered the 'consolidation phase' in 1964. DDT spray teams were disbanded *(5)*. In 1966, an editorial in *The Ceylon Medical Journal* warned of a potential epidemic because of extensive underreporting due to inadequate access to diagnosis by microscopy *(31)*.

In 1967, two outbreaks of *P. vivax* malaria were reported in two foci, which led to a major epidemic in Sri Lanka in 1967–1968 *(5, 32, 33)*. Districts in the intermediate zone of the country, including Kurunegala and Anuradhapura, were affected (Figure 1, 2) *(31, 32)*. IRS with DDT was quickly
reintroduced but, owing to emerging vector resistance, did little to stem the epidemic *(5)*. The epidemic has also been reported to be due to the complacency of malaria control officers and field workers, neglect of breeding areas, drug resistance and lack of domestic and foreign funding *(33)*. The number of reported cases reached 538 000 in 1969 *(34)*.

Resumption of malaria control (1970–1999)

After this resurgence of malaria, the Sri Lanka programme reverted to a strategy of malaria control. A decrease in the number of malaria cases occurred between 1975 and 1978, from 390 943 to 71 176 cases, an 81.8% decline. In 1983 the incidence began to increase again, resulting in a major epidemic, widespread throughout the country, in 1987, with 687 599 cases. The causes of this epidemic have been reported to include a shortage of regional malaria officers and relatively low rainfall in that

year *(35)*. Many reports link the epidemic to an irrigation and dam construction project on the Mahaweli River *(36)*, which was completed in 1987. The project was located in the malaria-endemic, eastern part of the country. Many uninhabited forest areas were cleared for the establishment of irrigated rice lands, and an estimated 1 million settlers moved from non-endemic areas of the country to this area within a short time.

During the same period, resistance of malaria vectors to drugs and insecticides began to emerge. The first report of chloroquine-resistant *P. falciparum* appeared in 1984 *(37)*, although another report indicated that limited testing had been done for drug resistance and most tests had shown high sensitivity to chloroquine *(35)*. At the same time, *Anopheles* resistance to malathion was also reported *(37)*.

In 1989, the malaria control programme was decentralized with headquarters of the AMC maintaining technical leadership of the programme, but implementation and management of financial resources being devolved to nine provincial programmes. Between 1990 and 1999, the number of confirmed malaria infections rose from 142 294 in 1995 to 264 549 in 1999 (Figure 3). The national annual parasite index (API) was 11.86 per 1000 population at risk in 1995 and reached a peak of 22.05 in 1999. The slide positivity rate was 13.0% in 1995 and 16.7% in 1999. The percentage of infections due to *P. falciparum* was 16.1% in 1995 and 23.7% in 1999. The number of deaths due to malaria infection varied from 14 in 1990 to a peak of 115 in 1998. In 1995, malaria transmission was concentrated mainly in the northern areas affected by the conflict as well as in north-central and south-east areas of the country. By 1999, high transmission was focused in the five districts of the northern region and in one district in the south-east (Moneragala).

Control to pre-elimination (2000–2011)

After a peak in 1999 of 264 549 cases, the incidence of malaria had decreased by 99.9% by 2011, when there were only 175 confirmed infections. The API also decreased, from 22.1 in 1999 to less than 1 in 2004. The slide positivity rate was 13.0% in 1995, peaked in 1999 at 16.7%, then decreased from 11.8% in 2000 to 0.2% in 2005. In 2010, the slide positivity rate was 0.001% (indigenous cases only). The vast majority of indigenous infections are now due to *P. vivax* (96.0% in 2011). The number of deaths attributed to malaria also decreased after 1998, with no deaths due to indigenous malaria since 2008. One death occurred in 2009 and one in 2011, both of which were imported cases from sub-Saharan Africa. Of the 175 reported malaria cases in 2011, 124 were indigenous. Studies with the polymerase chain reaction (PCR) assay have shown no evidence of submicroscopic parasitaemia in previously endemic areas of the country *(38, 39)*.

Figure 2 shows the changes in API in 2000, 2005 and 2010, with both indigenous and imported cases in 2000 and 2005 and indigenous cases only in 2010. The indicators changed in 2008, when Sri Lanka began to disaggregate cases according to whether infections were imported or indigenous.

FACTORS CONTRIBUTING TO CHANGING THE MALARIA SITUATION

Receptivity and vulnerability

RECEPTIVITY

Traditionally, malaria transmission in Sri Lanka has been considered endemic in the dry zone (the north, east and south-east); epidemic-prone in the intermediate zone (the north-west and western mountain slopes); and absent in the wet zone (the south-west) *(40, 41)*. In 1959, the spleen rates in these zones were 60% in the dry zone, 20–40% in the intermediate zone and less than 10% in the wet zone *(27)*. There is a marked seasonality in the annual number of indigenous cases, which peaks at the end of the north-east monsoon season, from December to March. A smaller peak occurs after the south-west monsoon, from June to October.

Malaria transmission has ranged from low to high over the years. IRS has helped to contain transmission to varying degrees. Recent introduction of vector control tools such as insecticide-treated nets (ITNs) and long-lasting insecticidal nets (LLINs) and new antimalaria treatment regimens have also probably reduced receptivity to malaria. Recent studies have shown low levels of parasitaemia in previously highly endemic areas, which are now reporting low case numbers *(38, 39, 42)*. In addition, entomological surveillance by the AMC shows that the numbers of the primary and secondary malaria-transmitting vectors, *An. culicifacies* and *An. subpictus*, respectively, are increasingly low, and locating sporozoite-infected mosquitoes is therefore becoming difficult. For that reason, no estimates of entomological inoculation rates are available for the past few years. Even with this reduced receptivity, however, the resurgence in 1967 and periodic epidemics over the years have shown that malaria can quickly be reactivated and cause major epidemics when vector control and surveillance measures are relaxed.

VULNERABILITY

As Sri Lanka is an island, it has reduced vulnerability to imported malaria. The conflict also tended to disrupt the number of foreign nationals entering Sri Lanka, whether for business or for leisure. With the cessation of conflict in 2009, however, arrivals in Sri Lanka via ports and airports have increased, and a 38% increase in tourism revenues was seen between 2009 and 2010 *(15, 43)*. Over 1 million foreign nationals entered the country in 2010 (Table 3) *(44)*, representing a 48% increase from 2005. While most foreign nationals are from non-endemic areas, some arrive from sub-Saharan Africa, China, India, and as far away as Haiti. In addition, increasing numbers of Sri Lanka citizens are returning to the country—from nearly 700 000 in 2005 to 1.1 million in 2010 *(44)*. Many of these are trained people who left to work in other countries as physicians, nurses and other professions, some of whom are working in malaria-endemic areas.

Table 3. Foreign passenger arrivals in Sri Lanka, 2010

Continent of origin	Number
Asia	504 962
Europe	401 193
North America	61 414
Australia	47 367
Africa	7 242
South America	1 394
Other	1 360

The closest country is only 29 km away: Sri Lanka's Mannar District on the western side is off the coast of the Indian state of Tamil Nadu. With the cessation of the conflict, there will probably be an increase the number of commercial and passenger boats to and from India. Group trips for Sri Lankans have been organized from India, now that it is safe to travel and live again in the northern areas. All these developments may increase the international importation of parasites and vectors into Sri Lanka.

Between 2008 and 2011, the number of imported cases more than doubled, from 23 cases in 2008 to 51 in 2011, and imported infections accounted for 29.1% of all infections in 2011. This number is likely to grow as economic development allows more travel into and out of this now peaceful country by foreign nationals and by Sri Lankans who are residing in or visiting malaria endemic parts of the world.

How was malaria controlled from 1970–1999?

VECTOR CONTROL

IRS was the main method of vector control during this period; however, community resistance to blanket-style spraying was reported, with very low acceptance in some areas, leading to difficulty in reaching the coverage required by the programme *(45)*. In view of reports of increasing resistance to DDT, malathion, an organophosphate, was introduced for use in IRS in 1975. Chemical larviciding with temephos (O,O'-(thiodi-4,1-phenylene) bis(O,O-dimethyl phosphorothioate), an organophosphate, was begun in 1977, and the product was applied irregularly during or before impending outbreaks, once every 10 days *(46)*. Larvivorous fish were reported to have been used throughout this time period.

After decentralization in 1989, IRS continued to be the main method of vector control, with perennial IRS conducted in all households in malarious districts. Between 1992 and 1993, however, widespread resistance to malathion was detected in *An. culicifacies*. Soon after, in 1994, the first synthetic pyrethroid, λ-cyhalothrin, was introduced for IRS, and other new insecticides followed. The introduction of pyrethroids may have increased community acceptance, which was already considered high (reported to be 90% in one study of the acceptability of malathion), as they emit less odour and do not leave a visible residue on walls *(47, 48)*. Following WHO recommendations issued in the mid-1990s *(49)*, the AMC Directorate initiated targeted spraying in areas known to have transmission, with high proportions of *P. falciparum* cases and with infections confirmed to be chloroquine-resistant and which were near vector breeding sites. An operational strategy of insecticide rotation was implemented in 1998 with a combination of up to six insecticides of two classes, organophosphates and pyrethroids. Insecticides were rotated between provinces, and occasionally between districts, with the aim of prolonging the useful life of insecticides and optimizing vector control.

While larvivorous fish had been used for vector control since the 1960s, use of this intervention began to increase in the mid-1990s as IRS coverage declined *(50)*. Fish were introduced before the malaria season, with re-introduction after each dry spell in gem pits (pits dug by gem miners) and other small breeding areas. In response to the increase in transmission subsequent to the Mahaweli project which was completed in 1987, vector control and larval source management were scaled up, with the participation of communities and the involvement of the irrigation and agriculture sectors through the strategy of integrated vector management *(51, 52)*.

Chemical larviciding was reported to be used as a supplementary control measure from 1997 in abandoned wells, gem pits and other areas and was considered cost-effective. Temephos continued to be used during this time, being applied irregularly during or before impending outbreaks, once every 10 days *(46)*.

ITNs were introduced only in 1999, with the support of a project financed by the World Bank.

PARASITOLOGICAL SURVEILLANCE

Parasitological surveillance was undertaken through an 'activated' passive case detection system, with specialized facilities for screening for malaria located in public health facilities. Case detection was strengthened by establishing more malaria diagnosis centers throughout the country. The personnel of these centres included two technicians from the AMC, a microscopist and a field officer, who prepared reports and administered treatment to people with a positive blood film. In addition to the case detection by specialized facilities, routine PCD continued in public clinics and hospitals.

The annual blood examination rate was 6.1% in 1995, with 89.8% of cases identified through the specialized 'activated' malaria diagnosis centers. In 1997, a World Bank international development assistance project was launched in Sri Lanka to support the revised WHO malaria strategy of 1993, comprising enhanced malaria control in six high-prevalence districts. The project supported active case detection (ACD) with screening of selected populations and treatment for positive cases. Nevertheless, at that time, ACD accounted for only a small percentage of positive cases (0.9%).

ENTOMOLOGICAL SURVEILLANCE

The entomological surveillance activities begun in the 1930s were continued throughout this period, by both the AMC Directorate and the regional malaria teams in each malarious district. Mosquitoes were collected by routine pyrethrum spraying in dwellings, cattle-baited nets, hut traps and window traps, and surveys of mosquito larvae were conducted in malarious districts at predetermined sentinel sites. Susceptibility tests and bioassays were used to detect evidence of insecticide resistance, and the results were used in planning IRS activities.

MANAGEMENT OF DISEASE

From the mid-1990s, it was recommended that all patients with fever be tested for malaria before treatment. Chloroquine and primaquine (0.25 mg/kg per day for adults) was used for *P. vivax*, with a 14-day regimen in low-transmission areas, and a 5-day regimen in other areas with higher levels of transmission. For *P. falciparum* cases, first-line treatment continued to be with chloroquine, with sulfadoxine-pyrimethamine as second-line treatment in the case of first-line treatment failure.

INTERSECTORAL COLLABORATION AND PARTNERS

In 1998, the President of Sri Lanka formally agreed to provide support for several activities in the WHO Roll Back Malaria programme. Approximately US$ 170 800 (11 287 300 LKR) was provided by the World Bank *(53)*. Between late 1999 and 2001, in five pilot districts with the highest mortality from malaria, activities were undertaken for early diagnosis and treatment, prevention with IRS, ITNs, larviciding and biological control, early detection and control of epidemics, community participation, operational research and programme management. Research projects were also undertaken, such as on drug resistance, combined drug therapy, a computer-based surveillance system, the efficacy of insecticide-treated curtains, and environmental management for malaria control.

How has malaria been brought to the brink of elimination during 2000–2011?

VECTOR CONTROL

Integrated vector management continues to be used for managing vector control in Sri Lanka, bringing together relevant sectors, community engagement and vector surveillance research to decide on which insecticides to use and to determine the most appropriate mix of vector control interventions, environmental management and larval control. The strategy has been successful in agricultural areas, where a combination of IRS, ITNs, LLINs and larviciding is thought to have contributed to the reduction in incidence.

The estimated coverage of the population at risk with IRS fluctuated during this period, but the general trend was for decreasing coverage, from 46.5% in 2000 to 22.5% in 2005. In 2008, with the decreased API, there was a shift to case-based and focal outbreak IRS. By 2010, national coverage had decreased to 5.9% of the

population at risk. Insecticide rotation, begun in the late 1990s, has continued, unless there are delays in the delivery of IRS supplies. In 2002, malathion was taken out of use because of mounting evidence of resistance.

ITNs have been distributed since 1999, and LLINs were introduced in 2004, with support from the Global Fund. Non-conflict districts were a priority for distribution of nets. These were distributed according to: the percentage of *P. falciparum* cases in the previous 3 years, the mortality rate, the number of pregnant women and children affected by malaria, proximity to a mosquito breeding site and the presence of internally displaced people or migrant populations. As security conditions changed frequently in the conflict zones, with associated displacement of populations, there was no formal process for distribution of nets in those areas.

In 2005, 14.8% of the population at risk was estimated to be covered by LLINs, and the proportion rose to 22.7% by 2009 and to 34.6% in 2010. The estimates are based on an average 3-year lifespan of an effective LLIN and an assumption of appropriate use. In a study on use of LLINs in 2008, it was estimated that 89.6–90.9% of respondents had slept under a LLIN the previous night *(54)*.

In the past decade, as support increased from the Global Fund to Fight AIDS, Tuberculosis, and Malaria (the Global Fund), larval control and environmental modification were used increasingly to reduce transmission. Even with the additional support, however, these methods were used on a relatively small scale, and monitoring and measurement of effectiveness were not well recorded. In 2001, it was estimated that 1 million people were protected by larvivorous fish *(55)*; however, in 2002 it was estimated that only 40 000 people were protected by this method *(55)*. Figure 5 and 6 illustrate larvivorous fish projects in Sri Lanka.

Pyriproxyfen, an insect growth regulator, was first procured in 2006 *(55)*. Two applications per year have been shown to be effective in inhibiting normal development of mosquitoes in gem pits, in controlling adult vector populations, in preventing malaria infections and in lowering the prevalence of infection *(56)*. The cost of this method has been estimated to be US$ 1 per treated gem pit *(56)*.

Recent studies in Sri Lanka have shown the effectiveness of larvivorous fish, larviciding and growth regulators in reducing vector density in the laboratory and in field sites such as dams, gem pits, brick-making fields and cement water tanks; little generalizable evidence is available worldwide on the effectiveness of larval control on malaria transmission *(57, 58)*. Other small-scale vector control measures include environmental modification, such as filling in gem and quarry pits and stream flushing. With Global Fund support, community groups filled abandoned gem mines and, in some instances, planted trees provided by a local nongovernmental organization *(59)*. The scale and scope of these efforts have not been well measured or documented.

Figures 5 and 6. Larvivorous fish distribution project in Kurunegala District (sign and breeding tanks)

ENTOMOLOGICAL SURVEILLANCE

Entomological surveillance has remained a core part of the overall malaria elimination strategy. In addition to continued surveillance by the AMC Directorate and regional malaria offices, a nongovernmental organization (Tropical and Environmental Diseases and Health Associates) has conducted entomological surveillance in its target districts as part of the Global Fund grant since 2008. Also in the late 2000s, 'farmer field schools' made the connection between vector control for health and for agriculture, educating and empowering farmers about the relations between public health and agriculture, and involving them in vector management *(60)*.

PARASITOLOGICAL SURVEILLANCE

The annual blood examination rate was 9.4% in 2000 and 5.0% in 2005, with little change up to 2010 (4.8%). As in the 1990s, the vast majority of confirmed cases were identified by activated passive case detection, accounting for 89.4% of infections in 2000 and 94.0% in 2005. In the late 1990s, the capacity for 'activated' PCD was increased when the number of microscopists in district hospitals was nearly doubled. ACD, which began in 1997, was scaled up and resulted in the detection of 1.1% of infections confirmed in 2000, rising to 13.1% in 2007. Mobile malaria clinics targeted mobile populations resulting from the conflict and remote, inaccessible populations in all areas in order to detect asymptomatic and symptomatic parasite carriers, including relapsing *P. vivax* cases, which can contribute to post-monsoon epidemics. Rapid diagnostic tests (RDTs) are occasionally used in these clinics, but most tests are conducted by microscopy. The Global Fund increased support for ACD in 2003, when funding started in Sri Lanka.

EPIDEMIOLOGICAL INVESTIGATION AND REPORTING

In 2008, the AMC Directorate introduced individual case reporting and stringent reporting of the type of infection, whether indigenous or imported, and whether in civilian or military personnel. A policy of case reporting within 24 hours was introduced 1 year later, and in 2010 a toll-free hotline was introduced. Cases are reported by e-mail or telephone. Private-sector clinics and physicians receive education campaigns in using the hotline to ensure reporting from all sectors. While there is a national health information system, the AMC uses a separate, web-based system in order to ensure reporting within 24 hours. The AMC expects to integrate the malaria reporting system into the national system once malaria is eliminated.

As the number of cases decreased after 1999, district staff had more time for case investigation. In 2009, the AMC Directorate instituted a programme of work for every confirmed or suspected infection, which includes follow-up of confirmed infections for 28 days after treatment, case investigation procedures and additional measures, such as screening for malaria in household members, entomological surveillance within 24 h and focal IRS within a 1-km radius (Annex 4). Also in 2009, the programme instituted review meetings, at which each case and the follow-up measures taken are reviewed in detail by AMC Directorate staff and regional malaria officers. The information from the case investigations and the case reviews is used to identify any changes in vector behaviour and to monitor parasite clearance time. The results of these investigations, in combination with mapping with geographical information systems, which began in 2009, are used for epidemic forecasting.

MANAGEMENT OF DISEASE

Global Fund support, beginning in 2003, allowed more people to be tested and treated for malaria. The protocol for diagnosis changed in 2007, when testing was recommended only for people with fever, a history related to malaria and symptoms such as body aches, joint pain, headache, nausea, vomiting or diarrhoea.

Treatment for *P. vivax* malaria remained the same (chloroquine and primaquine, as described above). The 14-day primaquine course that had been the policy only for low-transmission areas was extended nationwide in 2006 *(61)* to ensure radical cure or parasite clearance of both the blood and liver stages. The prevalence of G6PD (glucose-6-phosphate dehydrogenase enzyme) deficiency in Sri Lanka has been estimated to be relatively low (1–3%) *(62)*, and patients are not routinely screened for this condition before treatment. The national treatment

guidelines recommend that all patients with *P. vivax* malaria receive follow-up visits to ensure compliance with the primaquine regimen *(61)*.

In 1999, it was estimated that 51% of *P. falciparum* infections were resistant to chloroquine (first-line treatment), and by 2004 several cases of resistance to sulfadoxine-pyremethamine (second-line treatment) were detected *(61)*. As part of the malaria elimination strategy and as a result of an increase in the number of imported infections due to *P. falciparum*, artemisinin-based combination therapy, artemether-lumefantrine, was introduced in 2008. Primaquine has been used for treatment of the gametocyte stage of the parasite since 1956 or earlier *(6)*. The national treatment guidelines recommend that all patients with *P. falciparum* malaria be admitted to hospital for 3 days *(61)* (Annex 4).

LABORATORY SUPPORT: SURVEILLANCE, EXTERNAL QUALITY ASSURANCE AND CONTROL

Diagnostic monitoring has been consistent over the years. At district level, regional laboratories under the guidance of the regional malaria office collect and test all positive and negative slides. In addition, 10% of negative slides and all positive ones are sent to the central laboratory at the AMC Directorate in Colombo, which serves as the national reference laboratory. Public health laboratory technicians at district level who are found to perform poorly undergo refresher training.

Fourteen public health laboratory technicians at the central level are responsible for cross-checking every slide; this is probably an insufficient number. As part of Round 8 of the Global Fund Grant, an external organization was charged with designing, training staff and setting up a second, high-capacity laboratory for PCR testing.

HEALTH EDUCATION

The AMC used mainly external aid to conduct information, education and communication targeted to the general population and not specially for at-risk populations. The campaign supported by the Global Fund included the production of mass media materials, such as calendars, posters and radio programmes (Figures 7–9).

It is estimated that nearly 15 million people were reached with these tools during the Round 1 grant phase (personal communication, Dr Galappaththy, 30 December 2009) and 16 million during Round 4 funding. These methods have not been evaluated.

PROGRAMME MANAGEMENT

Maintaining essential staff such as microscopists was challenging during this period because of the conflict: in 1999, nine microscopists were trained in the region,

Figure 7. (left) Educational material for communicating treatment guidelines
Figure 8. (right) Educational poster for preventing malaria in pregnancy

and by the end of 2000 only three were still working in the government system *(63)*. In areas controlled by the LTTE, no Government training was provided, training by nongovernmental organizations was not accredited, and trained staff received insufficient compensation to keep them in their jobs *(63)*. Increased numbers of internally displaced people and the destruction of clinics and hospitals meant that fewer and fewer facilities carried an ever heavier burden *(63)*. Poor transport systems also made it harder to seek services.

Recently, malaria control programme staff have begun to undertake other work, such as in hospitals or as clerks. Furthermore, most staff in positions such as malaria supervisors are nearing retirement age, yet the Ministry of Health has no plans for a recruitment campaign. In one district, public health field officers are being transferred to positions such as clerks in medical institutions or as drivers or assistants; when they are needed for malaria-associated activities, they are usually released 1 week after a request. In another district, spray teams were reduced by half in 1998, and some were transferred to hospitals. Such transfers of malaria staff may be due to the low number of cases: administrators consider it unnecessary to maintain a position for malaria control. Regional malaria officers in three districts have reported difficulty in re-engaging staff members for IRS activities, even when they are needed.

Figure 9. Educational poster on surveillance for preventing and controlling malaria transmission

Increased funding from the Global Fund has allowed regional malaria officers and support staff to travel for supervision purposes. In addition, regular training has been conducted for all staff, from spray machine operators to public health inspectors, since 2003. The first malaria elimination training programme was held in late 2009, and spray machine operators, public health field officers and public health laboratory technicians receive annual training to keep them engaged.

Which populations are most affected by malaria?

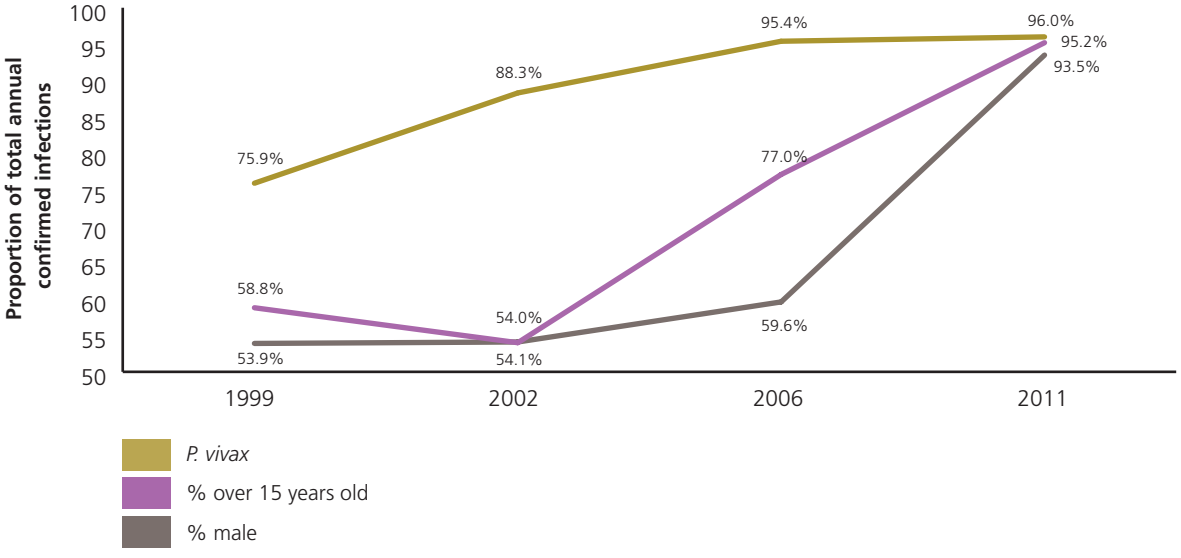
In the early 1990s, the populations most severely affected were in northern areas affected by the conflict and some parts of the endemic, north-central districts bordering the conflict area. Indigenous cases today are mainly concentrated in northern province, previously conflict-affected areas, and Hambantota District and Moneragala District in the southern province. These two districts were affected mainly due to presence of security personnel and environment conducive for vector breeding.

As national morbidity due to malaria decreased, the demographic profile of those infected changed. Adult males (aged 15–49) accounted for the majority of infections. Most infections were due to *P. vivax* rather than *P. falciparum*. The proportions of all confirmed cases in people over the age of 15 were 58.8% in 1999, 77.0% in 2006 and 95.2% in 2011 (Figure 10). Males accounted for 53.9% of all infections in 1999, 59.6% by 2006 and 93.5% in 2011. The proportion of indigenous infections due to *P. vivax* increased from 75.9% in 1999 to 95.4% in 2006 and 96.0% in 2011; 76.5% of imported cases were due to *P. vivax* in 2011. One infection with *P. ovale* was diagnosed in 2005, and one with *P. malariae* in 2008, which was acquired outside Sri Lanka.

These trends are due to the greater exposure of men with particular occupational and behaviour patterns involving greater mobility, outdoor work and work in more or forest-fringe areas, where *Anopheles* vector breeding is more common. These groups tend to have poor access to medical treatment and preventive measures, such as household vector control. Male gem miners and

Figure 10. Changes in population at risk for malaria, Sri Lanka, 1999–2011

1999, 2002 and 2006, both indigenous and imported cases; 2011, indigenous cases only



male security forces are particular risk groups for malaria infection. Others are considered to be people living along rivers and streams with high vector density, and mobile populations, such as chena (slash-and-burn) cultivators.

Infected gem miners are usually aged 18–50 years, have a low income level and are more likely than other groups to have poor living conditions *(64)*. In early 2010, the Anti-Malaria Campaign begun a collaboration with the security forces and police for diagnosis and treatment of malaria cases; as a result, the proportion of malaria cases among security personnel has been reduced. Throughout the first half of 2012, there were only a minority of security forces contributing to the total caseload in Sri Lanka.

How was malaria tackled in the conflict zone?

EPIDEMIOLOGY

In 1995, the API was similar in the 17 non-conflict districts (33.0) and the eight conflict districts (29.9). By 2000, however, the conflict districts accounted for the majority of infections, with an average API of 71.5 in conflict and 35.1 in non-conflict districts. In 2005, when the national incidence was considerably lower, the API in both areas was the same (0.4). Figure 2 shows the spatial distribution of API by district in 2000, 2005 and 2010, with the location of the conflict districts. Figure 11 and Table 4 show the numbers of cases in conflict and non-conflict districts.

The slide positivity rate was higher in conflict districts throughout most of the study period. In 1995, the rate was 17.0% in conflict districts and 11.7% in non-conflict districts. Similar to the API, by 2005, the slide positivity rate was the same in the two regions (0.2%).

PARASITOLOGICAL SURVEILLANCE

In conflict areas, most regional malaria officers and their staff remained at their posts and were provided with vehicles and RDTs to conduct mobile clinics whenever it was safe to do so. Sometimes, members of the LTTE assisted with and were beneficiaries of ACD mobile clinics. In addition, the Sri Lankan Red Cross, the International Committee of the Red Cross and Médecins Sans Frontières assisted in providing diagnosis and treatment services. A Sri Lankan private not-for-profit organization, Tropical and Environmental Diseases and Health Associates, trains and deploys microscopists to 'activated' PCD facilities in previous conflict districts as part of the Global Fund Round 8 grant, contributing to the scale-up of surveillance since 2009.

Figure 11. Numbers of cases of malaria in conflict and non-conflict districts of Sri Lanka, 1995–2010

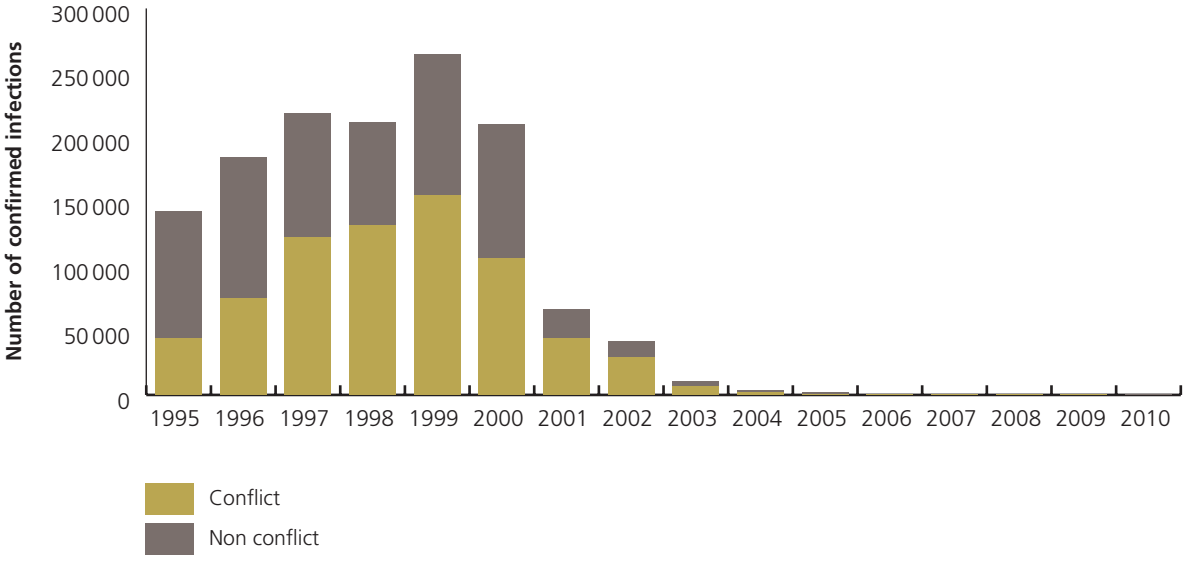


Table 4. Numbers of cases of malaria in conflict and non-conflict districts, Sri Lanka, 1995–2010

Year	Conflict districts	Non-conflict districts
1995	44 070	98 224
1996	74 628	109 691
1997	121 897	96 653
1998	131 797	79 894
1999	154 465	110 084
2000	105 612	104 427
2001	44 079	22 443
2002	29 168	12 243
2003	6 330	4 180
2004	1 685	2 035
2005	607	1 033
2006	179	412
2007	128	70
2008	180	187
2009	272	286
2010		684

With the collaboration of these agencies, surveillance was continued. The average annual blood examination rate in 1995 was 9.9% in conflict districts and 5.4% in non-conflict districts (Table 5). The rate in conflict districts increased to 18.5% by 2000, while only a minor increase to 7.9% was seen in non-conflict districts. By 2009, the rate had decreased to 10.4% in conflict districts and to 4.2% in non-conflict districts. The average per capita rate of ACD was slightly higher in conflict districts in some years because the mobile clinics targeted hard-to-reach at-risk populations, most of which were in the conflict areas. The rate in conflict districts peaked in 2008 at 6.3%, when 107 629 blood films were taken in these clinics; in that year, 0.4% of the population in non-conflict districts was tested in ACD mobile clinics.

PREVENTION

The AMC Directorate continued to conduct IRS in conflict districts and in those controlled by the LTTE, notwithstanding the challenges, including the risk posed by landmines. LTTE personnel assured the AMC Directorate of support for malaria control measures in their zones, partly because their combatants were severely affected by malaria. Regional malaria offices in

Table 5. Average annual blood examination rate and active case detection per capita in conflict and non-conflict districts, Sri Lanka, 1995–2010

Year	Conflict districts	Non-conflict districts
1995	9.9%	5.4%
1996	12.0%	6.2%
1997	15.4%	5.8%
1998	15.1%	5.9%
1999	20.2%	6.4%
2000	18.5%	7.9%
2001	13.4%	6.0%
2002	Not available	Not available
2003	15.4%	4.7%
2004	18.0%	4.3%
2005	14.3%	3.5%
2006	15.9%	3.7%
2007	16.1%	3.5%
2008	16.5%	4.2%
2009	10.4%	4.2%
2010	4.8%	4.8%

neighbouring stable districts reported that they assisted conflict districts throughout the years, coordinating IRS along and at times over the border. The Government sent supplies, including insecticides, to conflict districts with permission from the Ministry of Defense to send shipments via the sole accessible road to the north-east or, alternatively, by passenger ship. Communication between the LTTE and the AMC Directorate increased during the ceasefire, from 2002 to 2006, and supply delivery probably became easier during this period of relative calm.

Although the Ministry of Health and the AMC maintained a policy of providing all malarious districts with supplies, personnel and training, there were logistical challenges. In order to avoid indirectly supporting the LTTE, the Government usually provided only minimal supplies, and stock-outs of antimalarials occurred in some conflict-affected districts *(63)*. The communication nevertheless allowed continuation of IRS in the conflict zone. In 1995, the population at risk protected by IRS reached 23.5% in conflict districts, with higher coverage of 79.6% estimated in non-conflict districts. The population at risk in conflict districts that was protected increased to 52.2% in 2000 and 45.9% in 2005, representing higher levels of coverage than in non-conflict districts: 43.7% in 2000 and 10.9% in 2005.

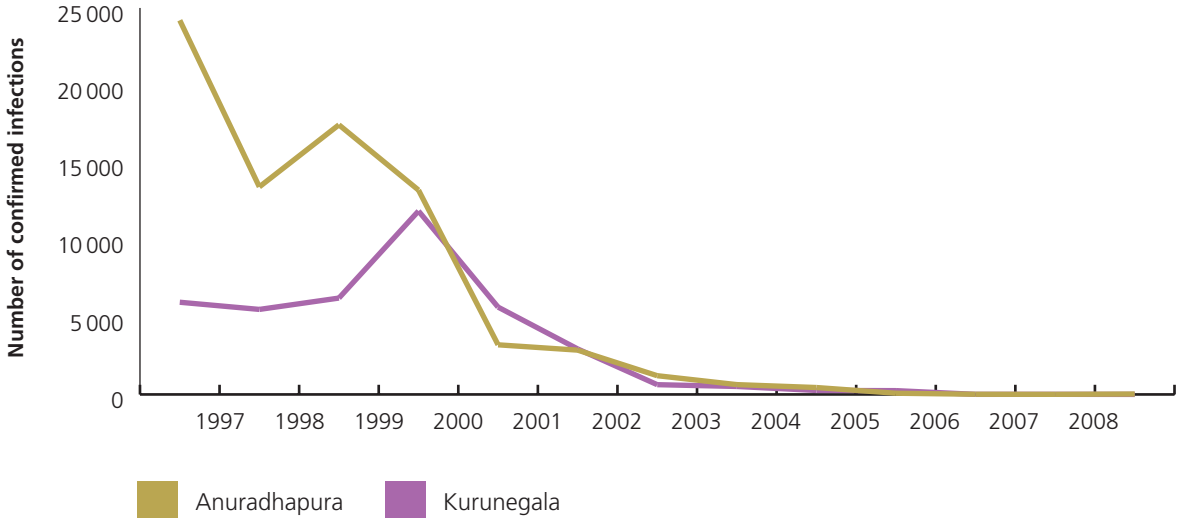
ITNs and LLINs were an important response to the higher case loads, internally displaced people and logistical challenges in conducting IRS in conflict districts. The Global Fund Round 1 grant supported the distribution of LLINs in conflict districts, and the Ministry of Health, with Global Fund grants, collaborated with a Sri Lankan nongovernmental organization, the Lanka Jatika Sarvodaya Shramadana Sangamaya (Sarvodaya), in distributing LLINs in northern conflict districts. The United Nations Children's Fund (UNICEF) and WHO also distributed LLINs. Through this network, it is estimated that enough LLINs were distributed to cover 38.1% of the population at risk in conflict districts in 2005 and 3.3% in non-conflict districts. By 2009, the estimated coverage had been maintained in conflict districts (40.9%) and had increased in non-conflict districts (19.1%).

How much has malaria control cost?

The cost of the programme in two previously high-burden districts, Anuradhapura and Kurunegala, was evaluated (Figure 2). As the AMC is part of a decentralized health system, detailed programmatic and costing data are kept at district level, managed by regional malaria officers and overseen by the Regional Director of Health Services.

The districts were chosen by AMC staff because of differences in their characteristics, the experience of the malaria programme managers and how safe it was to travel to the districts at the time of the study. Anuradhapura and Kurunegala are two districts in the largest area with known malaria transmission (Figure 12). Because of the difficulty in assembling costing data, two years were chosen, 2004 and 2009, to represent different phases of the district malaria programme as identified from epidemiological data and programme shifts, from endemic or

Figure 12. Numbers of confirmed cases of malaria in Anuradhapura and Kurunegala districts, 1997–2008



epidemic malaria (2004) to controlled low-endemic malaria (2009). As malaria programme staff also work on other vector-borne diseases, interviews and a review of job descriptions were used to determine the proportion of time spent working on malaria. Expenditure on personnel, travel, capital equipment, consumables and services was ascertained. Further information on the methods of data collection and analysis are shown in Annex 1.

The Sri Lankan Government and the Global Fund were and are still the main sources of funding for malaria control in Sri Lanka. Funding at district level is allocated by the ministries of finance and health, depending on risk and the available resources. Sri Lanka successfully applied for funding for its malaria programme from the Global Fund in rounds 1, 4, and 8, with approved grants of US$ 7.3 million in Round 1, US$ 3.7 million in Round 4 and US$ 21.6 million in phase 1 of Round 8. The AMC Directorate, in collaboration with the Ministry of Health and the Global Fund Country Coordinating Mechanism for Sri Lanka, determines which districts to include in grant proposals.

The initial estimates for the cost of eliminating *P. falciparum* and *P. vivax* malaria in Sri Lanka, according to the 5-year Global Fund Round 8 proposal budget projections, are US$ 1 per person and US$ 5 per person at risk *(10)*.

ANURADHAPURA DISTRICT

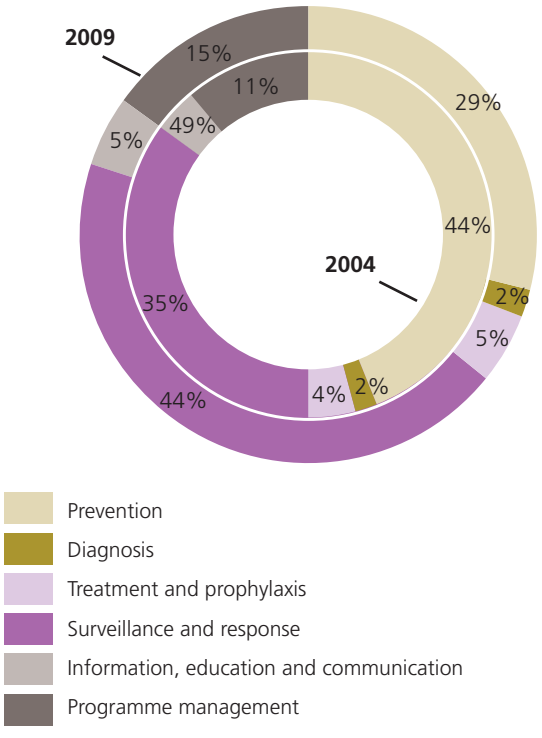
Anuradhapura District is located in the north-central area of the island. A peak of 24 202 cases was reported in 1997, with 636 cases in 2004 and 27 in 2009 (Figure 12). The District was never considered part of the conflict zone, although there was active conflict in the bordering districts of Mannar, Vavuniya and Trincomalee. Anuradhapura received support from the Global Fund during rounds 1 and 8 for 2004–2009.

In 2004, the estimated total expenditure on malaria was US$ 1 193 276. Prevention accounted for 43.6% of total expenditure, followed by surveillance and response (34.9%) and programme management (10.9%) (Figure 13). In 2009, total programme expenditure was US$ 656 928, with surveillance accounting for the majority of costs (43.7%), while expenditure for prevention dropped to 29.1% and that for programme management increased to 14.8%.

Personnel expenses accounted for 80.8% of the total in 2004, followed by travel expenses (11.7%) and capital equipment (5.1%). Consumables, services and training-related expenses represented the lowest percentage of total annual expenditure. In 2009, personnel expenses remained the highest cost for the District (74.0%),

Figure 13. Expenditure by intervention category in Anuradhapura District, 2004 and 2009

The inner circle represents 2004 and the outer circle represents 2009; the size of the circles does not represent a difference in total expenditure.



followed by capital equipment (12.7%); travel expenses increased to 8.5% of total expenditure.

Total annual programme expenditure decreased by 44.9% between 2004 and 2009. In both years of the study, most expenditures were for IRS, 'activated' PCD and routine PCD, surveillance, entomological surveillance and programme management planning and supervision. Between 2004 and 2009, the proportion of total programme expenditure for prevention decreased, while the proportion spent on surveillance increased. The reduction in expenditure on prevention (reduced by 66.1%) probably reflects the decrease in IRS: for example, the number of fully sprayed households in Anuradhapura decreased by 18% between 2004 and 2009; within that decline, the costs of personnel and travel for IRS decreased by 71.9%. By 2009, surveillance represented the largest proportion of total programme costs.

The decrease in costing between 2004 and 2009 may also be due to the fact that a high level of support was available from the Global Fund in 2004 and a lower level of support in 2009. Other changes might be attributable to a change in strategy instituted by a new regional malaria officer.

KURUNEGALA DISTRICT

Kurunegala District is in the North Western Province of Sri Lanka, a few hours by vehicle from the capital city of Colombo. It is in the intermediate climatic zone and is subject to frequent epidemics. The number of cases decreased from 5964 in 1997 to 516 in 2004 and then to 2 cases in 2009 (Figure 12). The district was never part of the conflict zone and did not border districts with active conflict. The district did not receive Global Fund support in 2004 but received funding in rounds 4 and 8.

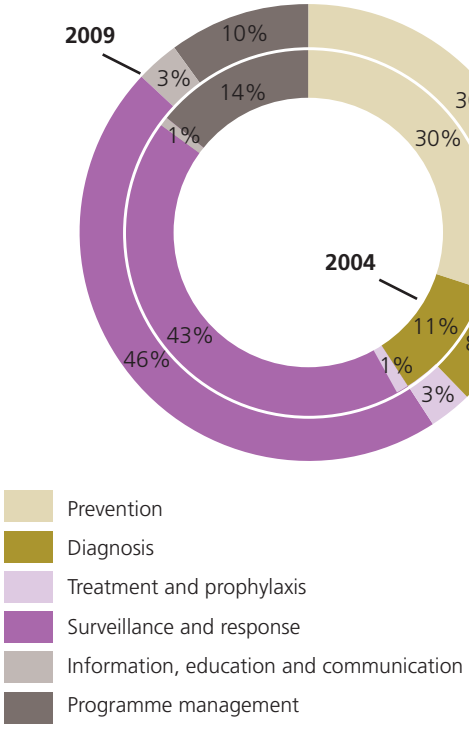
In 2004, Kurunegala reported a total expenditure of US$ 582 251. In that year, surveillance and response accounted for the majority of expenditure (43.1%), followed by prevention (30.1%) and programme management (13.7%) (Figure 14). Total expenditure in 2009 was US$ 501 176, with similar proportions for interventions as in 2004. Expenditure for surveillance and response remained highest at 46.4%, that for prevention was maintained at 30.3%, and that for programme management remained similar, at 10.2%.

Personnel costs accounted for 48.3% of total expenditure in 2004, and travel accounted for 45.7%. Most travel costs were for ACD, programme management and anti-larval activities. Consumables accounted for only 5.1%. In 2009, personnel costs increased to 67.5% of total expenditure, and consumables for IRS increased by 9.0%. Travel costs greatly decreased to 4.4%, due to a reduced budget for supervision.

The programme costs in Kurunegala were similar in 2004 and 2009, perhaps because the District had no Global Fund support in 2004. The added funding in 2009 therefore did not make dramatic changes, and only a slight increase was seen instead of the major decrease seen in Anuradhapura. Major costs, such as for routine PCD

Figure 14. Expenditure by intervention category in Kurunegala District, 2004 and 2009

The inner circle represents 2004 and the outer circle represents 2009; the size of the circles does not represent a difference in total expenditure.



and 'activated' PCD, entomological surveillance and programme management, all decreased. Expenditure for IRS increased slightly, by 7.2%, perhaps due to a reported increase in the number of fully sprayed households, from 5 129 in 2004 to 12 899 in 2009.

COMPARISON OF THE TWO DISTRICTS

Between 2004 and 2009, as the country moved from high-endemic to a period of controlled, low-endemic malaria, total expenditure and the types of costs changed in the two districts (see Annex 5 for further information). The cost per person at risk decreased by 48.1% in Anuradhapura but remained similar in Kurunegala (5.2% decline). Total programme expenditure decreased in both districts, although Anuradhapura had a larger percentage change. The proportion of costs spent on different categories of intervention changed extensively in Anuradhapura, from prevention to surveillance, but a similar change was not seen in Kurunegala, where surveillance and response activities continued to account for the majority of expenditures in both years.

How do the first and second attempts at elimination differ?

Sri Lanka experienced two periods of very low malaria incidence and is attempting to eliminate malaria from its borders for the second time. While there are some similarities in the strategies and tools used in the two attempts, there are some major differences as well. New tools and strategies are available today, and some lessons were learnt from the first elimination experience.

The first elimination attempt relied heavily on IRS with DDT to reduce transmission, with the aim of national coverage. While IRS is still the primary means of vector control, targeted, rational IRS is now used, with a strategy of highly targeted spraying in high-risk areas and for high-risk populations rather than blanket spraying. The choice of insecticides is also greater, allowing the rotation of several types and classes of insecticide. This strategy is used to decrease the risk of developing insecticide resistance, which was probably a factor in the unsuccessful result of the first elimination attempt. The use of different insecticides and highly targeted spraying may also have increased community acceptance of IRS.

The new vector control tools available today include LLINs, which are useful for groups that are difficult to reach through IRS operations. The role of LLINs was particularly important during active conflict, as they gave populations 3 years of protection when IRS teams could not reach the area for months or even years.

During the first elimination attempt, vigilance units were deployed for malaria surveillance, to investigate cases with ACD in cleared foci and to ensure that transmission was interrupted. This surveillance complemented PCD. However, it was noted in a 1961 WHO report that surveillance had not been intensive to the degree needed to find and eliminate the remaining parasite reservoir *(30)*. This failing was due to the scattered residual foci

in jungle areas, which had not been detected *(30)*. The programme today uses ACD as part of case investigations and among population groups that are hard to reach or have poor access to diagnosis and treatment, in addition to routine PCD and 'activated' PCD through the malaria screening and treatment centres. Case investigation is carried out for each case detected, and includes mass blood surveys to identify additional malaria cases in an affected area. Case review meetings, led by the AMC Directorate with regional malaria officers, allow feedback and discussion of best practices.

Reporting of cases and deaths was a priority in the first elimination phase. The programme has improved reporting by instituting reporting within 24 hours, with measures to increase reporting from private clinics and physicians.

The first elimination attempt relied on entomological surveillance teams to forecast potential epidemics on the basis of patterns of vector breeding. Today, monthly entomological surveillance continues, by both by the AMC Directorate and regional malaria offices, led by entomological assistants. These teams evaluate breeding sites and also the effectiveness of insecticides used for IRS, ITNs and LLINs.

Both elimination phases included radical cure of *P. vivax* cases and the use of primaquine for gametoctyocidal purposes in *P. falciparum* infections. Today, the new ACTs are used instead of chloroquine for *P. falciparum* cases, although primaquine is still used to eliminate gametocytes. The extended regimen as before is used for *P. vivax*, primaquine for 14 days, although adherence to the full dosage may continue to be a challenge.

LESSONS LEARNED

Between 1999 and 2011, Sri Lanka achieved a 99.9% reduction in the number of confirmed malaria infections. The API decreased rapidly from 22.1 in 1999 to less than 1 since 2004. In 2011, there were 124 indigenous cases. The number of deaths attributed to malaria also decreased after 1998, with none since 2008. Sri Lanka is now at a critical juncture, ready to move from pre-elimination to elimination of malaria within its borders. The country is therefore a leader in the South-East Asia Region, with Bhutan, the Democratic People's Republic of Korea, Nepal and Thailand, where the number of cases has also been reduced by more than half *(3)*. These low numbers have been maintained for 11 years.

This achievement is due partly to the flexibility of the malaria control programme. Willingness to introduce new evidence-based strategies probably allowed the country to reach today's status, from the introduction of new insecticides, new forms of ITN, new forms of treatment, to implementation of strategies such as integrated vector management, insecticide rotation, reporting within 24 hours and a toll-free line to report cases in the private sector.

Malaria programme experience

Sri Lanka benefits from a long history of malaria control and a strong PCD system. Entomological surveillance began in the 1960s, and this system of continual surveillance and feedback into programme management and decision-making continues today. Many resources are put towards surveillance. The country also has a long history of registration of civil information and vital statistics, which began in 1867. In the 1950s, the country was reported to have good record completeness. In addition, the country was one of the first to adopt the Global Malaria Eradication Programme reporting system of surveillance operations and to submit quarterly reports *(30)*.

Contribution of economic and social development to malaria control

Sri Lanka has experienced major economic growth during the past 15 years. The national per capita gross domestic product increased from US$ 715 (current prices) in 1995 to US$ 2375 in 2010 *(15)*, and total health expenditure per capita also rose, from US$ 26 in 1995 to US$ 84 in 2009. The adult literacy rate in Sri Lanka was estimated to be high (91% in both 2001 and 2006), and 76.6% of the population had access to electricity in 2009 *(15)*.

In 2010, Sri Lanka reported US$ 703 million net in official development assistance, or US$ 34 per capita *(15)*. The country also began to access more funding for malaria control and prevention. External funding contributed to strengthening the AMC. Roll Back Malaria, the World Bank and in particular the Global Fund all contributed to malaria control and prevention. Global Fund grants supported the travel for additional entomological surveillance and ACD mobile teams, as well as commodities such as LLINs.

Malaria in a conflict zone

The ability to adapt strategy led to the reduction of transmission in the conflict areas. As the conflict was centred in the known endemic zone of the northern and eastern districts as well as the epidemic central areas, the country was highly vulnerable to major epidemics. The AMC, working closely with the regional malaria officers, continued to undertake surveillance and vector control measures to the degree possible. New tools for vector control, such as new insecticides for insecticide rotation and LLINs for populations that may not have received IRS, assisted the programme. The AMC also formed partnerships with nongovernmental organizations and technical partners familiar with the conflict

areas. In the country as a whole, external aid was essential: the World Bank, WHO, and the Global Fund provided much support in scaling-up evidence-based interventions and their supervision in these zones.

Plasmodium vivax

As the number of malaria cases decreased, the proportion caused by *P. vivax* increased. In 1999, 76% of cases were due to *P. vivax*, and the proportion has remained over 95% since 2008. A similar trend has been seen in other countries with decreasing malaria transmission *(65)*; it may be linked to the successful treatment and vector control strategies that lower the *P. falciparum* burden faster than that of *P. vivax (65, 66)*. *P. vivax* is more difficult to eliminate than *P. falciparum* because more infections are asymptomatic and subclinical, with lower parasite densities, making detection more difficult; furthermore, the parasite cycle in the vector can exist at lower temperatures, and it includes hypnozoites, the dormant liver stage that causes relapses. A 14-day treatment regimen with primaquine is required to kill the hypnozoites, which complicates treatment adherence and has the side-effect of haemolysis in patients deficient in the G6PD enzyme *(67)*.

The AMC has had years of experience battling *P. vivax* malaria. The same treatment regimen, with 15 mg of primaquine, has been used since the early years of control and elimination, and the 14-day course was extended to the entire country in 2006. Enhanced surveillance measures, in particular ACD for identifying and then treating asymptomatic and relapse infections, have probably lowered transmission.

Financing

Adequate funding over the past 15 years, from both the Sri Lankan Ministry of Health and external sources such as the Global Fund, made it possible for these strategies to be implemented, even in the conflict zone. Funding for supervision and intensive entomological surveillance probably helped the programme to keep ahead of transmission.

While the costing exercise showed a 48% reduction in expenditure in Anuradhapura District, as the country moved from high endemicity in 2004 to controlled low-endemic transmission in 2009, a similar decrease may not occur once the country reaches elimination. National programme costs were estimated to be higher for elimination than for controlled low-endemic malaria in China, India, Mauritius, Swaziland and the United Republic of Tanzania *(68, 69)*, and Sri Lanka will probably have a similar experience. The costs will fluctuate with the rate of malaria importation, as it will define the extent of ACD and other methods needed to identify and treat imported cases, and the degree to which they can be shared for the control of dengue and other vector-borne diseases.

Plans for elimination

With the guidance and support of the Sri Lanka Ministry of Health, the programme has prepared a national strategic plan to eliminate malaria, and this objective is an important component of the 10-year national development plan *(70)*. The country plans to eliminate *P. falciparum* malaria by the end of 2012 and *P. vivax* malaria by the end of 2014. The decision to eliminate was based on national progress in health, education and communications, in addition to operational and technical strengths.

The current approach to elimination is based on strengthened surveillance, early reporting and case management with radical cure. Stratified case-based interventions will be implemented within integrated vector management and the scaling-up of existing elimination strategies, including border screening and treatment, case follow-up and investigation, formation of rapid response teams and a real-time information system. A mechanism for reporting malaria cases in the private sector is being established. An information, education and communication programme targets at-risk populations, and a parasite database with biological characterization of parasite populations will further strengthen control measures *(71)*.

The operational challenges of elimination, such as preventing reintroduction, are numerous *(72)*. Sri Lanka has difficulty in maintaining adequate cadres of trained personnel as well as financial commitment, particularly in the midst of a dengue epidemic and the global financial crisis. Without external support, pursuing elimination or strengthening the prevention of reintroduction will be difficult. If the momentum slows, there are historical precedents that suggest a dangerous resurgence is possible. Elimination must be seen as a "recurrent investment" *(2, 68)*.

THE FUTURE

Effective strategies for elimination and prevention of reintroduction should be based on further documentation of successful strategies, particularly maintaining robust, efficient surveillance and response systems and engaging other sectors. Most importantly, Sri Lanka must continue to identify and treat imported malaria infections *(73)*. The risk for importation will persist: tourism revenues increased by 38% between 2009 and 2010 *(15)*, ferry services have resumed from Tamil Nadu, India, to Colombo, and smaller boat traffic between the countries is likely to increase in the coming years *(74)*.

Of great importance is assurance of long-term, sustainable funding. Support for malaria programmes, in particular low-burden countries, by the Global Fund is at risk *(75)*. Sri Lanka was close to achieving malaria elimination once before, but reductions in funding were partly to blame for the devastating resurgence in the 1960s *(34)*. Repetition of history must be avoided, and a case must be made for continuing investment in Sri Lanka and other low-endemic and elimination settings. Countries can state their case better if they are armed with high-quality estimates of the cost of elimination and prevention of reintroduction.

Becoming malaria-free may further increase the surge in tourism on the island since the end of the conflict *(43)*; however, the other economic benefits are less well understood *(68)*. What is clear is that elimination will contribute to improving health in previous conflict regions and will generate a sense of national pride in a time of reconciliation. Sri Lanka has the national will, political commitment and operational and technical capacity to achieve elimination. Long-term internal and external momentum and support must be maintained for this ambitious programme to succeed.

Conclusions

Sri Lanka is a country that has made progress towards malaria elimination against severe challenges. A major national conflict continued for nearly 30 years, creating an obstacle to implementation of malaria control. The country's main malaria burden is due to *P. vivax* infections, both historically and currently, and special efforts—treatment with adherence to the proper dosage of primaquine or another effective regimen—will be needed to eliminate even the dormant liver stage of the parasite. Although these challenges are important, the country maintained interventions even in conflict-affected areas, continually introduced new evidence-based interventions and strategies and plans to continue strengthening the surveillance and response systems essential for elimination. The story of progress in malaria elimination in the Asia-Pacific region is often neglected; this case-study adds to the growing literature of both successes and challenges in this region.

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ANNEX 1: DATA SOURCES AND METHODS USED

Comprehensive component

DATA AND LITERATURE REVIEW

Published and unpublished literature was reviewed before field collection and then again during and after data collection in the country. A search was conducted on Google, Google Scholar, Pubmed, the WHO library (WHOLIS) *(1)*, the WHO South-East Asia Regional Office *(2)* and the website of the Global Fund to Fight AIDS, Tuberculosis and Malaria. References were also found in the bibliographies of relevant publications. The review included grey literature from the AMC Directorate and offices of the regional malaria officers during field data collection, such as annual reports, administrative reports and plans and grant reports.

Data on malaria testing and incidence were taken from routine surveillance records of the AMC Directorate and regional malaria officers for 1995–2011. The AMC Directorate provided district-level annual estimates of population at risk, IRS activities and distribution of ITNs and LLINs.

INTERVIEWS

Thirty-three semi-structured interviews were conducted on the basis of a guide at the AMC Directorate in Colombo and in the offices of the regional malaria officers and the medical officer of the health area in the districts of Ampara, Anuradhapura and Kurunegala. Seven interviews were conducted at the AMC Directorate, with managers, entomological and parasitological laboratory staff and accountants. A total of 19 interviews were conducted at the offices of the medical officers of the health area in the three sample districts, with programme managers, entomologists, technical support staff, IRS spraymen and drivers. One interview was conducted with an accountant at the office of a regional director of health services. No interviews were conducted outside the public sector. A 'purposeful sampling method' was used to identify knowledgeable people for the interviews. The AMC Directorate programme manager identified five medical officers of health areas with extensive experience, who in turn suggested other staff members for interviews on the basis of the topics in the interview guide and gaps in data. Verbal consent was obtained before each interview.

ANALYSIS

A conflict variable was created, whereby districts considered to be 'non-conflict' were those under Government control with no indication of active conflict. The sources of data for this variable were conflict maps of the Sri Lanka Ministry of Defense and the LexisNexis Academic database *(3)*. If there was a difference between these two sources, the Ministry of Defense reports were considered decisive.

The quantitative and qualitative data were reviewed to identify factors that had contributed to the decreased incidence of malaria in Sri Lanka, including an estimate of coverage by vector control and surveillance in conflict and non-conflict districts. Information from the literature found in the desk review before commencement of field work was used to formulate the tools for collecting quantitative and qualitative data, such as the interview guide and Excel spreadsheets for surveillance data. These documents and grey literature, accessed during and after data collection, were used to identify the main changes in malaria control strategies and interventions. These preliminary findings were compared with the qualitative and quantitative data collected in the field. In later stages of analysis, these documents were used to fill gaps in data or to confirm or question conclusions derived from the interviews and quantitative data.

Annual data on malaria incidence, surveillance and vector control activities by district were plotted in Microsoft Excel. Major malaria indicators and coverage estimates were calculated, and trends over time were derived. Major political, socioeconomic and environmental trends, especially in conflict districts, were reviewed. All the trends were then compared with each other by data triangulation, defined as the review, synthesis and interpretation of data from multiple sources *(4)*. If there was any difference among data sources in the case-study, the interviews were considered the primary source of information.

Costing component

DATA COLLECTION

As the AMC is part of a decentralized health system, detailed programme and costing data are housed at district level, managed by regional malaria officers and supervised by the regional director of health services. The costs of commodities such as LLINs were found by reviewing records and by interviews at the AMC Directorate.

Expenditures were determined for two of the largest malarious districts, Anuradhapura and Kurunegala, which were chosen because of their different characteristics, the experience of the malaria programme managers and the safety of travel to the districts at the time of the study. As it was difficult to obtain costing data, two years were chosen, 2004 and 2009, to represent different epidemiological data and programmatic shifts in the district malaria programme, from endemic or epidemic malaria (2004) to controlled low-endemic malaria (2009). As malaria programme staff also worked on other vector-borne diseases, interviews and a review of job descriptions were used to determine the proportion of time spent on malaria.

ANALYSIS

The costing analysis does not include expenditures or contributions to the malaria programme from non-public sector entities, such as households, nongovernmental organizations or Global Fund support through organizations outside the public sector. The sources of information on costing were paper and electronic files and interviews. Interviews were conducted with staff to determine the percentage of time dedicated to malaria-related interventions (prevention, diagnosis, surveillance and response, information, education, communication and programme management), excluding activities such as dengue prevention. In order to determine the time allotted to various interventions in 2004, staff were asked whether they had spent more or less time on each intervention than in 2009. Their responses were compared with the programmatic trends described by regional malaria officers and epidemiological data on intervention coverage.

Costs were categorized as those for personnel, travel, equipment, consumables and services and were also grouped by type of intervention: prevention, diagnosis, treatment and prophylaxis, surveillance and response, information, education and communication and programme management. The costs of equipment were amortized by straight-line depreciation. All costs were converted into 2009 United States dollars with national deflators and 2009 representative country exchange rates *(5, 6)*. As costs at district level included contributions from the regional director of health services, the district budget and the Global Fund, funding provided by the national Ministry of Health for malaria (e.g. for some personnel) was estimated and allocated proportionally for each intervention in the two districts. The national budget report was used to determine funding provided by the Ministry of Health. The 2008 national budget report was used to calculate funds provided for malaria in 2009, whereas costs in 2004 and 2008 were assigned to districts as proportions of total district spending on malaria control.

Limitations

Trends in malaria epidemiology for this case-study were derived from national surveillance data. The study did not include estimates of the number of unreported infections or of infections in people who did not seek treatment. Data from local and international nongovernmental organizations and from the private clinics that participated in malaria control, prevention, diagnosis and treatment were not used.

The interviews were conducted with a 'purposeful sampling' method, from initial contacts supplied by the programme manager. This may have resulted in selection bias; however, the interview participants in the case-study represent a wide range of positions and experience, from programme managers to technical officers to indoor residual sprayers, thus reflecting the experience of decision-makers and those closest to the work.

The costing analysis did not account for expenditures made through nongovernmental channels or private expenditure by households. Data from a small sample of two districts were collected and analysed; while the costs therefore cannot reflect those of the entire country, they provide a basis for comparing two phases in the same district and perhaps against each other.

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ANNEX 2: DEMOGRAPHIC DATA, ADMINISTRATIVE DIVISIONS, POLITICAL ORGANIZATION AND SOCIAL AND ECONOMIC DEVELOPMENT, SRI LANKA

Demographic data *(1)*		
Variable	**Year**	**Value**
Population (thousands)	2011	20 869
Population sex ratio (male per female)	2011	0.974
Percentage aged 0–14 years	2011	24.9
Percentage aged 15–64 years	2011	66.7
Percentage aged 65 years and above	2011	8.4
Percentage of women aged 15–49 years	2011	66.7
Annual population growth rate (%)	2011	1.04
Crude birth rate (live births per 1000 population)	2010	18.2
Crude death rate (deaths per 1000 population)	2010	6.6
Infant mortality rate (deaths per 1000 live births)	2010	14.2
Life expectancy at birth, males/females (years)	2010	71.7/77.9

The adult literacy rate in Sri Lanka in 2005–2010 was estimated to be 91% *(2)*. The percentage of appropriate age groups enrolled in primary school in 2010 was 94%, which is just below that of the United States (95%) *(2)*.

The Gini index is a measure of "the extent to which the distribution of income (or consumption expenditure) among individuals or households within an economy deviates from a perfectly equal distribution". In 2007, the index for Sri Lanka was 40.3, which was similar to that of an upper-middle income country, Thailand (40.0), but lower than that of a lower-middle income country, the Philippines (43.0).

The gross domestic product grew by 8.0% between 2009 and 2010, 1 percentage point higher than the average for lower-middle income countries *(2)*.

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ANNEX 3: NATIONAL HEALTH AND HEALTH ECONOMIC INDICATORS, 2010

National health and health economic indicators in Sri Lanka, 2010			
Indicator	**Year**	**Value**	**Source**
External resources for health as percentage of total expenditure on health	2010	2.97	World Bank *(1)*
General Government expenditure on health as percentage of total expenditure on health	2010	44.24	World Bank *(1)*
General Government expenditure on health as percentage of total Government expenditure	2010	5.77	World Bank *(1)*
Total expenditure on health as percentage of gross domestic product	2010	2.95	World Bank *(1)*
Out-of-pocket expenditure as percentage of private expenditure on health	2010	81.19	World Bank *(1)*
Per capita Government expenditure on health at average exchange rate (US$)	2010	31	WHO *(2)*
Per capita total expenditure on health at average exchange rate (current US$)	2010	69.96	World Bank *(1)*
Private expenditure on health as percentage of total expenditure on health	2010	55.3	WHO *(2)*
Social security expenditure on health as percentage of general Government expenditure on health	2010	0.1	WHO *(2)*

Health indicators, Sri Lanka, 2009 and 2010			
Indicator	**Sex**	**Value**	**Year**
Life expectancy at birth (age, years)	Male	71.73 *(2)*	2010
	Female	77.87	2010
	Both	74.72	2010
Adult mortality rate (per 1000 population 15–59 years)	Both	182	2009
Children under 5 mortality rate (per 1000 live births)	Both	14	2010
Maternal mortality ratio (per 100 000 live births)		35	2010

Distribution of years of life lost by cause, 2009			
Cause	**Year**	**National**	**Regional**
Communicable diseases	2008	11% *(2)*	
49%			
Noncommunicable diseases	2008	39%	36%
Injuries	2008	50%	15%
Percentages reflect proportions of total years of life lost			

References

1. World Bank. The world databank. Washington DC, 2010.
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ANNEX 4: SCOPE OF WORK TO BE PERFORMED WHEN MALARIA INFECTION IS DIAGNOSED *(1)*

1. Before a patient who tests positive for malaria is treated, the species of *Plasmodium* should be identified, either by examining blood smears for malaria parasites or by a rapid diagnostic test (RDT) test for malaria antigens.
2. Before initiating treatment, blood should be collected from all patients who test positive for malaria (confirmed either by blood smear or RDT) for barcoding and genotyping of the parasite species that caused the infection.
3. When malaria treatment has been started or already completed without the above measures, the diagnosis of malaria infection should be confirmed or excluded by the detection of malaria antibodies in peripheral blood.
4. A specimen of venous blood should be collected from all patients with clinically suspected malaria who were not investigated before initiation of antimalaria treatment to determine the presence or absence of malaria antibodies. This test should be done before, during or within 4 weeks after completion of antimalaria treatment.
5. All blood specimens for examination should be collected (into tubes), stored and transported within the time stated in the Anti-Malaria Campaign (AMC) guidelines.
6. As the diagnosis and the effectiveness of treatment are assessed by further examinations, all positive blood smears and RDT kits, 10% of negative blood smears and 10% of negative RDT kits should be stored appropriately and sent to the AMC headquarters.
7. Patients with confirmed malaria should be treated according to the guidelines of the Department of Health (General Circular No. 01-14/2008 issued by the Director General of Health Services). Note that in the above circular it is mandatory to treat all *Plasmodium falciparum*-infected patients as inward patients.
8. The medical institution in which the patient received a diagnosis should notify the area regional medical officer immediately after diagnosis, preferably by telephone (regional medical officer location and contacts).
9. The area regional medical officer should take the responsibility for investigating the case.
10. Other relevant regional medical officers and the medical office of the health area (in which the patient stayed or visited in the previous 2 weeks and where the patient is staying during and up to 4 weeks after treatment) should also be notified by the area regional medical officer as early as possible, at least within 48 h.
11. All cases of malaria should be investigated by the staff attached to the respective regional medical and medical office of the health area in which the patient stayed or visited in the previous 2 weeks.
12. During follow-up field visits, adherence to primaquine treatment for the prescribed period should be ascertained for patients who had *P. vivax* malaria by assessing the number of tablets remaining with the patient and the number of days left for completion of the full course of treatment.
13. The regional medical officer should ensure that a minimum of three doses of primaquine are administered under direct observation during case investigation and follow-up visits.
14. Blood smears should be examined on days 7, 14, 21 and 28 for *P. vivax*- and on days 2, 3, 7, 14, 21 and 28 for *P. falciparum*-infected patients to assess the

efficacy of treatment, to confirm the absence of parasitaemia after completion of treatment and to ensure 100% compliance with treatment.

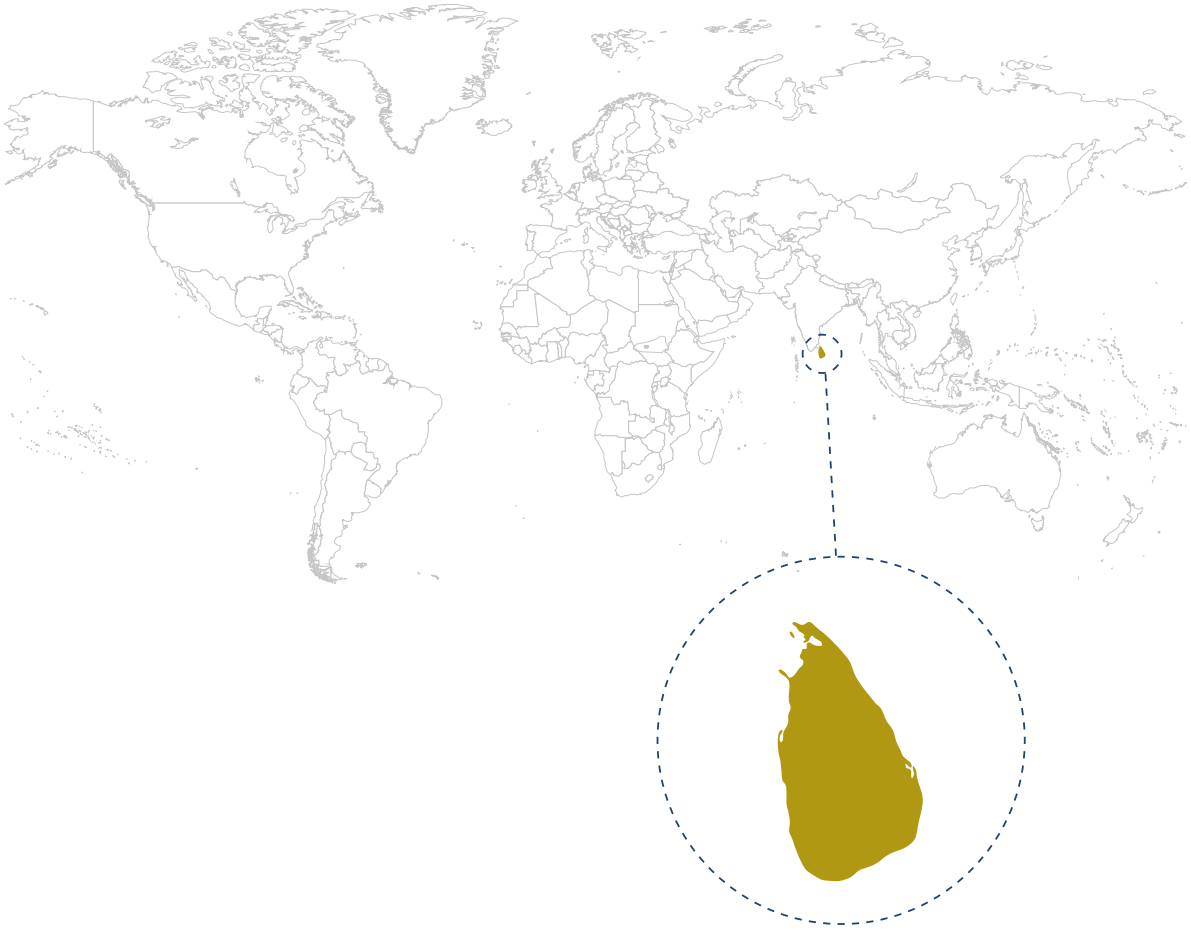
15. In case investigation, all household contacts and residents living within an approximately 1 km radius should be screened for malaria parasites by examining blood smears or detecting malaria antigens with a RDT, and insecticides should be sprayed on all the inside surfaces of the house in which the patient stayed during the fortnight before diagnosis and all the dwellings within an approximately 1 km radius (focal indoor residual spraying) within 2 weeks of diagnosis.
16. Entomological investigations and relevant vector control in the area should be completed within 2 weeks of diagnosis of the case.
17. The population should be informed about the natural history of malaria transmission and what they should do to protect themselves from malaria infection.
18. Forms to be completed after case investigations should be filled in and sent to the AMC headquarters by the regional malaria officer or officers within 2 weeks of completion of treatment.

References

1. Anti-Malaria Campaign. Colombo, 2012. http://www.malariacampaign.gov.lk/Precentation/NewCaseDetection.aspx. Accessed 1 August 2012.

ANNEX 5: ADDITIONAL COSTING DATA FOR ANURADHAPURA AND KURUNEGALA DISTRICTS, SRI LANKA, 2004 AND 2009

Costing element	2004		2009	
	Anuradhapura	Kurunegala	Anuradhapura	Kurunegala
Global Fund round funding	1	N/A	8	4, 8
Annual expenditure (US$)	1 193 276	582 251	656 928	501 176
Total population	773 227	1 491 313	820 000	1 708 042
Cost per person (US$)	1.54	0.39	0.80	0.29
Estimated population at risk	773 227	304 884	820 000	277 060
Cost per population at risk (US$)	1.54	1.91	0.80	1.81
Expenditure for prevention (%)	43.6	30.1	29.1	30.3
Expenditure for surveillance (%)	34.9	43.1	43.7	46.4
Expenditure for programme management (%)	10.9	13.7	14.8	10.2
No. of cases	636	516	8	6



This case-study is part of a series of malaria elimination case-studies conducted by the World Health Organization (WHO) Global Malaria Programme and the University of California, San Francisco (UCSF), Global Health Group. The case-studies series documents the experience gained in eliminating malaria in a range of geographical and transmission settings with the aim of drawing lessons for countries that are embarking upon elimination.

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