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Malaria and Climate Change

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Malaria Control and Climate Change in India

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Abstract

Since the earliest records began, malaria, or very similar fevers, have been recorded throughout India. The disease imposes enormous human and economic costs on the country and despite significant effort and expenditure to control the disease, the National Anti-Malaria Programme (NAMP) is unable to take effective control. We examine the historic malaria control efforts and the successes of malaria control programmes after the Second World War. DDT played an important role in this control programme and we discuss the role played by this insecticide and the subsequent pressure to ban or restrict it.

While climate can affect the incidence of malaria, it is increasingly clear that man's economic activities and malaria control strategies play a far larger role in the incidence of the disease. By concentrating on the role played by climate in the spread of malaria, attention and resources are diverted away from activities that could reduce the incidence of the disease far more effectively.

Although malaria is preventable, there are a number of factors that hinder the successful control of the disease in India. These factors, such as excessive bureaucratic involvement, a lack of accountability and environmental pressure, are discussed and we make several recommendations as to how these obstacles could overcome.

Introduction

On the 4th of July 1898, a malaria researcher working in Calcutta made an astonishing discovery. After working for several years trying to discover the way in which the malaria plasmodium parasite was transferred from mosquitoes to humans, Dr. Ronald Ross, a British military doctor, discovered that the mosquito's bite transmitted the most devastating disease known to mankind. Dr Ross, who was initially a somewhat reluctant researcher and part time novelist, received the Nobel Prize for his discovery.

The malaria parasite had first been identified by Charles Louis Alphonse Laveran in 1880 while he served as a military doctor in Algeria. It took a further 18 years and much persistence to prove that the parasite spent part of its life cycle in humans and part in mosquitoes and that the mosquito's bite bridged the two. Recognising the role played by the mosquito in transmitting malaria led researchers to one of the most effective ways of stopping the disease – vector control.

While there are numerous references to malaria in Roman text and later in numerous Shakespearean plays, the ancient Hindu text the Atharva-veda[1] contains a number of references to malaria. The Atharva-veda specifically details the fact that fevers were particularly common after excessive rains (marhavasha) or when there was a great deal of grass cover (mujavanta)[2].

Other ancient writings also make references to malaria or malarial-type fevers in India. The Caraka Samhita, one of the ancient texts on Ayurvedic medicine which was written in approximately 300BC and the Susruta Samhita written about 100BC both refer to diseases where fever is the main symptom. The Caraka Samhita classifies the fevers into five different categories, namely continuous fevers (samatah), remittent fevers (satatah), quotidian fevers (anyedyuskah), tertian fevers (trtiyakah) and quartan fevers (caturthakah).[3]

Long before the British colonised India, malaria was a serious problem for the country and it seems that no one was beyond the deadly reach of the disease. In 1351, the much feared and ruthless ruler, Sultan Muhammed bin Turghluk contracted malaria while on a military campaign against rebels and within a short time succumbed to the disease (Dalrymple, 1994).

While malaria has imposed enormous economic costs and a great deal of human misery on India, some of the great successes in controlling the disease were achieved in India. Formal malaria control programmes were started under British colonial rule and continued after Indian Independence in 1946. One of the most remarkable periods in Indian malaria control began with the introduction of DDT around this time. This extraordinary insecticide eradicated malaria from southern Europe and the United States and proved to be the most effective weapon against the disease at the time. As this paper will explain, DDT is still a necessary component of almost all malaria control programmes and despite the highly charged attacks against its use, should not be abandoned. This study examines the successes and failures of malaria control in India and we go on discuss the potential impact of climate change on the spread and incidence of the disease. We make several broad policy recommendations policy that could result in improvements in the malaria control programme.

[1] The *Atharva-Veda* is one of four ancient Hindu religious texts and is attributed to a sage, or *rishi*, named Atharvan, and consists of a number of hymns and magical incantations. Some scholars believe that this scripture may have originated with the original pre-Aryan culture of indigenous peoples, and because it deviated from the other *Vedas*, it was not at first readily accepted. Eventually it too was adopted as a ritual handbook by the Brahmans, the highest class of priests. (http://www.sacred-texts.com/hin/av.htm)

[2] This could have been at times of heavy rains and high temperatures, which would have made the grass grow faster and would have led to increased breeding pools for mosquitoes and would have led to faster development of adult mosquitoes.

[3] Tertian fevers are so called because the fever recurs every other day, as the parasite (in this case Plasmodium vivax) goes through its life cycle in only forty eight hours. Quartan fevers refer to the fact that the parasite's life cycle (in this case Plasmodium malariae) lasts seventy two hours, with fevers therefore recurring every third day.

Early Malaria Epidemics

Understanding infectious diseases became a high priority for the colonial British governments. Diseases, such as malaria, leishmaniasis and sleeping sickness, were not only dangerous for British forces in their attempts to enforce military rule, but threatened civilian populations that settled in the various colonies around the globe.

Unfortunately, no systematic studies were performed prior to 1961 and so one has to rely on more ad hoc records and studies taken from different areas of India. Records show just how devastating malaria was in the early days of the British occupation of India.

Malaria epidemics in the Punjab and Bengal both show a startlingly high morbidity and mortality. At the time the efficacy of quinine as a treatment for malaria was well established, however it is probable that there were insufficient supplies for widespread treatment and that individuals did not seek medical attention quickly enough.

Table 1 details recorded deaths from malaria in the Punjab between 1869 and 1908. So frequent and severe were these epidemics that it is difficult to imagine how these areas not only managed to replenish their populations, but maintained economic and social activities.

Table 1 Malaria Epidemics in the Punjab

Year	Area	Period	Number of Deaths	Mortality rate
1869	Punjab	October & November	116,540	Unknown
1876	Punjab	October & November	174,238	Unknown
1878	Punjab – Ludhiana, Jullinder & Hoshiarpur	October & November	180,356	Unknown
1879	Punjab	October & November	141,996	Unknown
1884	Punjab	-	-	Records show mortality rate to be 30 higher than normal
1892	Punjab	-	283,223	Unknown
1894	Punjab	October & November	132,767	Unknown
1900	Punjab – Ludhiana, Umballa, Karnal, Gurdaspur & Raya	-	254,580	Unknown
1908	Punjab – Amristar, Delhi, Palwal, Miani, Gugarat	-	307,316	Amristar – 62.5 per 1000 population Delhi – 100 per 1000 population Palwal – 420 per 1000

				population. Miani – 403 per 1000 population Gujarat – 247 per 1000 population

Malaria epidemics occurred throughout India with varying intensity. Sir Gordon Covell, the one-time head of the Malaria Institute of India, records epidemics of "great intensity" in Murshidabad (Bengal) in 1821. In 1852, one malaria epidemic wiped out the entire village of Ula and then spread across the Bhagirathi River to Hooghly and continued to devastate populations for many years in Burdwan.

The development of the Indian railways under the British administration contributed to the spread of malaria. The rather haphazard construction of railway embankments provided a number of breeding sites for the malaria vectors. It is also likely that the labourers that worked on the construction of the railways introduced different strains of the parasite to the areas in which they worked, possibly increasing the incidence of the disease.

In the early 1920s, Bengal suffered a severe malaria epidemic which resulted in over 730 000 deaths in 1921 alone. Thereafter, the number of deaths from malaria slowly decreased to within 300 to 400 000 per annum. During the Second World War however malaria deaths rose again, particularly in 1943, when Bengal recorded over 680 000 deaths and in 1944 when there were an appalling 763 220 deaths from the disease. This latest epidemic resulted in part from an unprecedented famine in Bengal, which is likely to have compromised the immunity of the population. It is also possible that the malaria rates increased during the Second World War because the authorities would have been concentrating on defending India from possible invasion.

Bombay, in many respects the economic hub of modern India, has suffered greatly from malaria epidemics. Early literature on Bombay makes frequent references to the unhealthy conditions of the island and its' surrounds. Table 2 details the number of admissions of malaria cases to medical institutions in Bombay.

The construction of major infrastructure, such as railroads or bridges was often associated with increases in malaria rates. This could be due to the fact that labourers were imported from other areas, not only increasing the population, but introducing a new reservoir of malaria parasites. In addition, most labourers would have lived in close quarters, ensuring a relatively easy transmission of the disease. Bentley records that there were significant outbreaks of malaria during the construction of the Colaba causeway between 1821 and 1841 and during the construction of Alexander Dock and Hughes Dry Dock (Bentley).

The number of malaria cases in Bombay increased relatively sharply after 1901, during which time the construction of the railway was completed, ensuring an increase in traffic and a greater movement of people.

Table 2 Malaria Incidence in Bombay (Mumbai)

Year	Number of malaria cases
1890	9,911

1891	13,264
1892	13,723
1893	13,174
1894	13,424
1895	13,597
1896	8,417
1897	4,345
1898	6,170
1899	9,811
1900	10,190
1901	23,597
1902	34,217
1903	38,148
1904	48,539
1905	46,461
1906	51,181
1907	55,364
1908	63,938
1909	54,839

Of course, malaria was not only a problem for civilian populations, but, as Sultan Muhammed bin Turghluk discovered to his cost, it was a serious danger to the military. Among British troops in 1921, over 30% of all hospital admissions were for malaria and in 1922, 10 552 cases of the disease were reported, with 26 deaths out of a total military force of 60 166. This represents an incidence rate of 175 per 1000 which increased slightly to 180 per 1000 in 1923. It is notable that the mortality figures were kept to within very low limits, with only 17 deaths from 10 875 cases in 1923. This is surely testament to the availability of effective and timely treatment.

The number of cases among the Indian troops is broadly similar to that of the British troops, with 173 cases per 1000 in 1922. However, the mortality rate among Indian soldiers was around 3 times higher than for British soldiers. It is possible that this was because Indian soldiers did not have access to the same level of medical care and treatment offered to the British soldiers.

Early Malaria Control

Early malaria control efforts tended to concentrate on the removal of breeding sites and later used chemicals such as the larvicides Paris green[4] and kerosene. One of the first formal operations to control the disease took place at Mian Mir, near the city of Lahore. Mian Mir was named after the Sufi saint that was buried there in 1635 and had great spiritual importance for Mughal rulers.[5]

[4] Paris Green or copper aceto-arsenite, was first discovered by the firm of William Sattler at Schweinfurt in Germany in 1814 as a green pigment used in paints (http://www.webexhibits.org). Its properties as a larvicide were not discovered until the 1920s after experimentation by two Americans, Barber and Hayne (Harrison, p. 186).

[5] www.mughalgardens.org

Mian Mir later became a British military post and the focus of a concerted effort to eradicate malaria. Mian Mir had an intricate system of irrigation canals which provided excellent breeding grounds for the malaria vectors. The incidence of malaria was astonishing, with an average incidence of slightly under 100%, rising to over 300%[6] during epidemic years.

The malariologists Drs. J.W.W. Stephens and S.R. Christophers, arrived at Mian Mir in 1901 with ambitious plans to remove all the breeding sites, evacuate the infected people and administer quinine as both a curative and preventative measure.

Both Stephens and Christophers had witnessed the attempts to control malaria in Freetown, Sierra Leone, the first of Britain's West African colonies. The Freetown malaria control programme had failed because Dr. Ronald Ross, who was posted there to fight malaria, underestimated the number of breeding pools and the sheer number of vectors that he was trying to control. Ross had very limited funding and the best available technology was to pour oil on the numerous breeding sites around Freetown.

The problem was not only that Ross severely underestimated the number of breeding sites, but he didn't appreciate that as soon as the oil treatments stopped, breeding would begin again. Ross redoubled his efforts with increased funding from private sources and ensured the removal of all potential breeding sites, including rubbish, broken bottles and other potential water containers. Despite these concerted efforts, the programme was remembered more for its impact on the Freetown's rubbish than with malaria control.

Despite the fact that Stephens and Christophers had seen the programme fail in Freetown, they both believed that malaria could be dramatically reduced at Mian Mir. Their programme began in 1901 and eventually developed into a massive effort, with between four and five hundred soldiers set to work full time at filling in the irrigation canals. The programme of constantly filling in ditches and removing puddles and any other potential breeding site continued until 1909. During 1909 there was a serious malaria epidemic, as there was in 1908 throughout the Punjab, and the courageous, but ultimately useless control programme was abandoned.

As Harrison points out, the experience at Mian Mir proved "... that the mosquito was a much more formidable enemy than had previously been admitted, especially in its adaptability to attack, its capacity to cover considerable distances and make use of, as it were, secondary breeding places, when those of first choice were closed. It proved above all that in malaria control every local situation needed to be reconnoitred and a tactic tailored to it" (Harrison, p. 135).

While the control efforts at Mian Mir were taking place, other larviciding operations were under way in Bombay, Jhansi, Poona, Meerut, Secunderabad and at all other military posts. Specific details of the success of these control operations are not available; however it is likely that without long lasting larvicides, such as Paris Green, they would have been costly and not particularly effective in the long term.

In 1917, the Bengal Nagpur Railway (BNR) and the East India Railways formed a separate malaria control organisation, specifically to control the disease in and around stations. A

[6] A malaria incidence of 300% would mean that every person would suffer 3 bouts of malaria during a single year.

similar strategy was followed in South Africa, where the National Railways managed to dramatically reduce the incidence of malaria among its staff though a comprehensive larviciding programme.

Similar larviciding and breeding pool removal programmes were undertaken during the 1920s in the tea plantations of Assam and in Mysore by the Rockefeller Foundation[7]. In 1927 the Central Malaria Bureau was expanded and renamed as the Malaria Survey of India.

The first reported aerial spraying of Paris Green is reported to have taken place in 1937. Paris Green, as mentioned above was first used in malaria control in the 1920s and was an important technological advancement as it could be spread over a large area, such as a swamp or riverbed that would have been inaccessible on foot. Paris Green was also favoured because it was non-toxic to fish, could be safely used around cattle (perhaps of particular importance in India) and at watering holes and was easy to transport. Paris Green, unlike other pesticides, was also safe for the pesticide sprayers to handle and could be easily transported (Harrison, p. 186).

At the same time, Paris Green was being successfully used in other malarial areas such as South Africa and Brazil. The famous malariologist, Fred Soper, favoured the use of Paris Green in Brazil, where he headed malaria control operations for the Rockefeller Foundation. Soper's efforts, while costly, managed to eradicate two of the main malaria vectors *Aedes aegypti* and *Anopheles gambiae* from Brazil in 1934 and the mid 1940s respectively.

In 1938, pyrethrum was first used in malaria control in Delhi. Pyrethrum, which is a natural insecticide derived from the chrysanthemum flower, was first used shortly after the turn of the century by William Gorgas[8] in Cuba where it was burned inside sealed dwellings. Fumigating houses in this manner however, was inconvenient and time consuming.

In around 1910, the German scientist G. Giemsa was experimenting with different ways of using pyrethrum and developed a way of spraying pyrethrum on walls with a spray pump. This method took over two decades to catch on, and it was used with great success in South Africa for the control of malaria on sugar estates (Harrison. p.210). Pyrethrum acts as a 'knock-down' insecticide, in that it kills the mosquito on contact, unlike other insecticides, such as DDT that act on the insect's nervous system and will kill only after a few hours (Desowitz, p.63).

The Rockefeller Foundation began using pyrethrum sprays experimentally in India to great success and this method of malaria control was recognised as enormously valuable. The use of pyrethrum was then expanded to Assam by Dr. D. K. Viswanathan, the well known Indian malariologist in 1942.

All of the above interventions would have had some impact of the incidence of malaria, yet they were unable to sustain the control of the disease. The success of any malaria control programme without long-lasting insecticides was bound to be short-lived with vast breeding areas and colossal numbers of malaria vectors. Moreover, the use of pyrethrum sprays in

[7] The Rockefeller Foundation was founded by the oil tycoon, John D. Rockefeller in 1901 with the aim of promoting the well being of mankind.
[8] William Crawford Gorgas was, like Dr. Ronald Ross, an army major and medical doctor and worked with Ross to eradicate malaria from Panama so that the Panama Canal could be constructed.

houses and cattle sheds was effective against the *An. culicifacies* vector, but was not effective against *An. fluviatilis* and *An. minimus* (Subbarao, 2002).

Malaria control was about to change dramatically however. During the Second World War, the Allied forces began using a new insecticide to halt the spread of tick-borne typhus and other vector borne diseases. As soon as the remarkable efficacy of the chemical was noted, DDT was adopted by malaria control programmes around the world. The next section will describe the use of DDT and the Global Malaria Eradication Programme.

DDT and the Hope of Malaria Eradication

DDT was first synthesised by Othmar Zeidler in 1874 but the chemical remained in obscurity until 1939, when Dr. Paul Müller discovered its insecticidal qualities while working at Geigy. During the Second World War, diseases spread by parasites and ticks proved to be a significant problem for troops and civilians alike. DDT was doused over people by the liberating Allied forces to kill parasites and was highly effective at controlling diseases, typhus in particular.

DDT was first used in India by the armed forces in 1944 for the control of malaria and other vector borne diseases. In 1945, DDT was made available for civilian use in Bombay to control malaria and shortly afterwards in 1946, pilot schemes using DDT were set up in several areas, including Karnataka, Maharashtra, West Bengal and Assam. Between 1948 and 1952 the WHO set up DDT demonstration teams in Uttar Pradesh, Rayagada, Wynad and Malnad.

The distribution of DDT in Bombay produced some remarkable results within a very short period. On 1st July 1945, the first civilian home was sprayed in India with a 5% solution of DDT mixed in kerosene. This would have produced a spray concentration of approximately 5 mg/m^2 which is a higher concentration than is currently used in DDT vector control. This initial spraying ensured that not a single adult *An. fluviatilis* from any house was found either during daytime or night time catches. The use of DDT was not only popular among the locals for control of the deadly Anopheles mosquito, but the insecticide also ensured that lizards, cockroaches, scorpions, bedbugs and ticks all disappeared after a single spraying.

Of course, the most important benefits were not simply in the control of irritating pests, but in the improvements in life expectancy. After the spraying in the Kannara district, it was reported that the population began to grow precisely because of a decrease in the death rate as a result of the DDT spraying. Prior to DDT being used, the district reported an average of 50,000 malaria cases every year, which was reduced by around 97% to only 1,500 cases after DDT was introduced.

The spray programme in Bombay took place during a period of great upheaval in India and the withdrawal of the British Raj from the Sub-continent. Despite the difficult and highly-charged times, Mahatma Gandhi found the efforts important enough to send his blessings to the project. The importance of this blessing should not be underestimated as there were and are religious purists who object to the killing of any fellow creature, including mosquitoes[9] (Harrison, p. 241).

[9] In order to appease those who objected to the use of DDT on religious grounds, Dr. D.K. Viswanathan explained that spraying DDT inside a house was like putting barbed wire around the house. The malaria control

During 1949, it is estimated that over 6 million people in Bombay were protected from malaria through the use of DDT and that at least half a million cases of malaria were prevented. Along with the control of malaria came the control of a number of other diseases. The incidence of human plague was completely eliminated and there were reports of reductions in the incidences of diarrhoea and dysentery. It is likely that this was because the numbers of insects that contribute to the spread of these diseases were all dramatically reduced. The benefits were not restricted to people; cattle also enjoyed improved health as the ticks that can cause festering sores and infections were all but destroyed.

In the early 1950s India's population was estimated to be around 360 million and every year around 75 million people suffered from malaria and approximately 800,000 died from the disease. The disease put almost the entire population at risk and the country had, and still has, over forty different anopheline species. Of these, *An. culicifacies, An stephensi, An. minimus and An. fluviatilis* are the major vectors of the disease.

The apparent health and economic benefits that came from using DDT prompted the formation of the National Malaria Control Programme (NMCP) in 1953. The control programme first set out to control the disease in the endemic and hyperendemic areas with 125 control units. Each of these control units consisted of between 130 and 275 men and their plan was to protect approximately 1 million people each. Teams of inspectors were required to inspect the houses that had been sprayed in order to ensure that the spraymen were completing their tasks correctly and that the insecticides were effective.

By 1958, the malaria control programme had been increased to protect at least 165 million people from the disease with 160 control units. Controlling the disease became an issue of economic importance. A study conducted in the early 1950s estimated that there would be a net gain of 200 million rupees if the government spent 40 million rupees to control malaria (Rao).

After consultation with the WHO and with the assistance of UNICEF and the US Agency for International Development (USAID) the decision was made to attempt the eradication of malaria. The programme was expanded to cover the entire country with an additional 230 units and the National Malaria Eradication Programme (NMEP) was born.

The control units were divided up into sub-units, sectors and sections where the sections each had the task of protecting around 10,000 people from malaria. This meant that on average each section would be responsible for spraying 2,000 houses once during the high transmission season (if the area was in a seasonal malaria area) or twice every year in those areas where transmission occurred year round.

The entire eradication plan was based on the spraying of DDT[10] and the provision of chemotherapy to those in need. Based on the experience from the NMCP, it seemed reasonable to expect that eradication could be achieved in just a few years and originally the

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officers would not be forcing the DDT onto the insect, rather the insect was choosing to enter the house, take a blood meal and then kill itself by landing on the walls (Harrison, p. 242).

[10] The prescribed manner of spraying DDT was to mix 5% suspension of DDT wettable powder in water into a compression sprayer and to pump it to a pressure of 40 pounds per square inch. The sprayer would then stand about 18 inches away from the wall and spray the mixture onto the wall in a sweeping motion so that the DDT would be left on the walls at a concentration of 2 grammes per square metre (Harrison, p 243).

plan was for 365 of the 390 NMEP units to stop spraying by 1960/61 and only to undertake surveillance.

As it turned out however, controlling malaria was not that simple. Initially there were some outstanding results. The number of cases fell dramatically and it seemed as if the days when there were over 75 million cases of malaria and 800,000 deaths per year were over. In 1961, the number of cases recorded officially was just under 50,000. Even if this official number underestimated the actual number by 3- or 4-fold, the numbers of cases averted and lives saved was colossal.

By the early 1970s it became apparent that controlling one of the most devastating diseases known to man was not going to be achieved solely with the use of DDT. Malaria rates began to rise again from below 50,000 in the early 1960s to well over 1 million in 1971.

Eradication Fails

There are numerous reasons behind the increase in the incidence of the disease. One of the major problems with the eradication programme was that the supervisors could not manage to inspect all of the buildings that had been sprayed. It may have been ambitious to expect each control team to protect 1 million people from malaria, and perhaps the inspectors would have been able to perform their functions better if they had fewer houses to inspect.

Along with this, there was a decline in the morale of the spray men and inspectors. Spraying houses and other structures day in and day out cannot be considered a stimulating profession. As soon as the numbers of malaria cases were reduced, it perhaps was not even particularly rewarding. It has been widely reported that there was a great deal of complacency within the control teams and even within the management of the NMEP.

Without strong management and rigorous inspections, the sprayers began to miss out houses that should have been sprayed and those that were sprayed were frequently done incorrectly. In 1970 a joint mission by the WHO and USAID found some alarming shortcomings in the malaria eradication programme. According to the report, of the 96 spray units operating in the area inspected, covering a population of 40 million, only 11 could claim to have achieved a coverage of 90% of the houses for which they were responsible.

One village in particular was singled out by the report. The village contained 63 houses of which 10 had been passed by because they were locked. The residents of 15 houses had refused the sprayers admittance and another 20 agreed only to have the verandahs, store rooms and cattle sheds sprayed. One house was overlooked completely. This meant that only 17 of the 63 houses (or 26%) were adequately protected.

Under these circumstances, resistance to DDT began to develop in certain areas, particularly in *An. culicifacies* and *An. stephensi*. This resistance continues to be a problem today, however resistance is not a justification for the removal of DDT from the current malaria control programme, as will be discussed below.

The complacency of the sprayers seems to have been shared by the general population, as people turned the sprayers away, so it seems unfair to lay the blame for the resurgence of the disease entirely at the feet of the control teams. In addition, road labourers, dam builders, railway construction workers, herdsmen and other migrant workers that had semi-nomadic lifestyles not only spread new reservoirs of the parasite, but made it difficult for the spray teams to offer them any kind of protection.

During the mid 1960s, the distribution of insecticides was subject to delays and disruption due to the Indo-Pakistan War. The disruption of the war ensured that some areas were not sprayed, even if the spray men were sufficiently motivated to do so.

Matters did not improve in the mid-1970s with the steep increase in oil prices. DDT, which is a petroleum product, increased in price along with oil and the country ran short of the insecticide (Harrison, p. 253).

Apart from the problems that beset the vector control teams, those people that had contracted malaria were not guaranteed to be able to get effective and timely treatment. Delays in examining blood films meant that treatment was not given in good time. The uni-purpose workers that dealt only with malaria cases were changed to multi-purpose workers by the Ministry of Health and Family Welfare. This meant that workers that previously only had to focus on malaria now had to deal with a wide range of ailments and diseases.

Furthermore, malaria cases were not treated properly. There was a steady increase in the number of *Plasmodium falciparum* malaria cases and a decline in the proportion of *Plasmodium vivax* cases. While the *P. falciparum* does not recur, as *P. vivax* does, it is a more deadly version of the disease.

In 1969, many governments had seen their eradication plans fail and the World Health Assembly that met in Boston demanded that the eradicators change course. No longer were they to rely solely on DDT as a method of eradication, but they were required to take into account local conditions and to the realities of managing the programmes in developing countries.

Several years later, the WHO's Malaria Eradication Division changed its name to the Division of Malaria and Other Parasitic Diseases. India was not the only country that had failed to eradicate the disease. Sri Lanka had similar astonishing victories against malaria, but it soon resurged as it did in parts of Africa and Latin America.

Table 3 Positive cases of malaria in India (1961 to 2000)

Year	Cases	Deaths
1961	49,151	
1962	59,575	
1963	87,306	
1964	112,942	
1965	99,667	
1966	148,012	
1967	278,214	
1968	274,634	
1969	347,975	
1970	694,017	
1971	1,322,398	
1972	1,428,649	

1973	**1,930,273**	
1974	**3,167,658**	**3**
1975	**5,166,142**	**99**
1976	**6,467,215**	**59**
1977	**4,740,930**	**55**
1978	**4,144,385**	**74**
1979	**3,064,697**	**196**
1980	**2,898,140**	**207**
1981	**2,701,141**	**170**
1982	**2,182,302**	**187**
1983	**2,018,605**	**239**
1984	**2,184,446**	**247**
1985	**1,864,380**	**213**
1986	**1,792,167**	**323**
1987	**1,663,284**	**188**
1988	**1,854,830**	**209**
1989	**2,050,064**	**268**
1990	**2,018,783**	**353**
1991	**2,117,460**	**421**
1992	**2,125,826**	**422**
1993	**2,207,431**	**354**
1994	**2,514,217**	**1,122**
1995	**2,926,197**	**1,161**
1996	**2,870,082**	**1,010**
1997	**2,660,605**	**879**
1998	**2,222,789**	**666**
1999	**2,284,713**	**1,048**
2000	**1,950,765**	**941**
2001(up to Sep'01_	**653,960**	**265**

The next section will deal the more recent outbreaks of malaria in India and the contemporary problems facing the malaria control teams. This will be followed by conclusions and recommendations.

Recent Malaria Epidemics and Control Strategies

It appears that the official number of malaria cases has stabilised at around 2 million cases per annum, with changes to this dependant on many factors, such as climate and movement of people. There are many examples of severe outbreaks or epidemics of the disease that are noteworthy.

On 11th October 2000, a sample survey was taken in the Betul District of Madhya Pradesh, which found that of the 1.47 million residents, 73% or 1.07 million tested positive for *Plasmodium falciparum*. The high incidence of the disease can be put down to the fact that the scheduled spraying of DDT in the area only covered a fraction of the targeted houses. Those houses that were sprayed were found to have plastered over the walls, rendering the DDT residue useless.

An outbreak of the disease occurred in Jhadina and other villages of Garhmukteshwar in the district of Ghaziabad during September and October of 2000. Slide tests showed that 12.8% of the 78 blood slides were positive for *Plasmodium falciparum* which prompted mass radical treatment for 3,700 people. In addition to the chemotherapy offered, a spray programme was initiated using 25% malathion (as a residual insecticide), and themphos (as a larvicide). Despite these measures, surveys conducted afterwards revealed that 27.3% of the population carried the *Plasmodium falciparum* parasite.

In one of India's poorest states, Orissa, epidemiological data for the Kalahandi, Bolangir and Koraput districts between 1997 and 1999 reveals that over 80% of the population were positive for *Plasmodium falciparum*. One of the major contributors to the high incidence of the parasite prevalence is that there is drug resistance to chloroquine and alternative chemotherapies are not available. The state also lacks the funds to purchase and transport insecticides to the affected areas.

One of the highest parasite prevalences was found in the Aligarh District in Uttar Pradesh, where the population of over 185,000 is mostly rural and lives in small villages or settlements. A survey conducted during 2000 revealed that between 94.7% and 100% of the population tested positive for *Plasmodium falciparum*. In the village of Iglas, where the Pf% was 91.6%, no spraying of houses had taken place for at least 10 years and there are reported to be many potential breeding pools for the main vector in the area, *An. culicifacies*.

While the official number of cases of malaria is around 2 million, it is widely accepted that this is a great underestimation of the true number of cases. Estimates made by many malaria researchers range from between 10 million to over 30 million. Many sufferers choose to seek private treatment for malaria and never report to state clinics or hospitals, even if they are available.

As in many countries, the National Anti Malaria Programme (NAMP) relies on both chemotherapy and vector control in order to control the disease. The chemotherapy strategy relies on the early detection of cases and prompt treatment with effective therapies. One of the major challenges that healthcare workers face however, is that malaria cases frequently do not seek treatment at clinics until the fevers are quite advanced. In many rural areas, clinics or other places of treatment are inaccessible or too expensive for families, further delaying or eliminating the possibility of treatment.

The current treatment regime for suspected cases is a single dose of chloroquine phosphate – 600mg (4 tablets) is given and for confirmed cases of *P.vivax,* a single dose of 600mg chloroquine and 15 mg Primaquine (for 5 days). For confirmed cases of *P.falciparum* a single dose of 600 mg chloroquine and 45mg Primaquine (single dose) is given. In chloroquine-resistant areas, the treatment for *P.falciparum* is Sulphalene/sulphadoxine (1500 mg)+ Pyrimethamine (75 mg) and Primaquine (45mg).

Drug resistance is a serious problem in India as almost every malarial state reports resistance to chloroquine. There are also reports of resistance to sulphadoxine-pyremethamine, the alternative to chloroquine in Assam, West Bengal, Madhya Pradesh and Karnataka. There are also reports of resistance to quinine and mefloquine. To date there is no reported distribution of artemisin-based therapies, which have been successfully introduced in south east Asia and South Africa where resistance has occurred.

Table 4 below details the consumption of insecticides used in the malaria control programme. DDT remains the most used insecticide, at 7,000 metric tonnes at 50% concentration, followed by Malathion, at 1,500 metric tonnes at 25% concentration. In addition to the adulticides, which aim to kill the adult mosquito, three different larvicides are also utilised, however in relatively small quantities.

Table 4 Consumption of Insecticides in Public Health Sprays

Insecticide	**1997–98**	**1998–99**	**1999–00**	**2000–01**
Adulticides				
DDT 50%	7489MT	5800MT	7000MT	7000MT
Malathion 25%	575MT	2500MT	2200MT	1500MT
Malathion (technical)	20.5 L	34.5 L	20.0L	20.0L
Synthetic Pyrethroid	-	-	1.5Kl	11Kl
Larvicides				
Fenthion	50Kl	84Kl	60Kl	70Kl
Temephos	175Kl	NA	36Kl	40Kl
Pyrethrum Extract	NA	175Kl	20Kl	20Kl

Source: Malaria Research Centre (ICMR)

Widespread resistance to these insecticides is common in India. The Malaria Research Centre reports double, triple and quadruple resistance among the major vector *An. culicifacies* and in parts triple resistance among *An. stephensi*. As is shown in Table 5 below, *An. culcifacies* is resistant to DDT in 18 of the 28 states, which severely hampers the use of the insecticide.

Table 5 Present Status and Geographic Distribution of Insecticide Resistance in Indian Malaria Vectors

Vector	**Type of resistance**	**No. of states**	**No. of Union territories**	**Total No. of districts**
Anopheles culicifacies	DDT	18	2	286
	Double	16	2	233
	Triple	8	1	71
	Quadruple	2	-	2
Anopheles stephensi	DDT	7	1	34
	Double	6	1	27
	Triple	3	1	8

Where: Double – DDT & BHC
Triple – DDT, BHC & Malathion
Quadruple – DDT, BHC, Malathion & Synthetic Pyrethroids.

(Subbarao, 2002)

Resistance is also reported to exist to Dieldrin among some of the malaria vectors. While the insecticide resistance does pose a number of considerable challenges to the malaria control programmes, the solution is not necessarily to remove the insecticides completely from the control programme.

While *An. culicifacies* is one of the most widespread of the malaria vectors, it is not necessarily the most effective or efficient transmitter of the malaria parasite. *An. fluviatilis* is far more efficient a transmitter of the disease as it is entirely anthropophagic, (it only feeds on man). By contrast, *An. culcifacies* is zoophagic (feeds on animals) as well as anthropophagic, which reduces dramatically the probability that it will transmit malaria.

Studies undertaken in the Sundergarh District of Orissa Province show that *An. fluviatilis* has a biting rate of 14.6/man/night, compared with *An. culicifacies's* biting rate of only 0.3/man/night (Subberao, 2002). *An. fluviatilis* is found only in forested areas, while *An. culicifacies* is found in both plains and forested areas and the ability of *An. fluviatilis* to transmit the parasite ensures that the transmission load in the forested areas is 0.61 bites/person/day compared with approximately 0.0 bites/person/day (i.e. negligible) in the plains area.

Not only is *An. fluviatilis* highly effective at spreading the deadly malaria parasite, but it is 100% susceptible to DDT. This alone should be reason enough to keep DDT within the Indian malaria control programme. Finding new insecticides that are effective against those vectors that exhibit resistance is, of course, crucial.

The Malaria Research Centre in New Delhi has tested a range of alternative insecticides with a view to using them in the field. These insecticides, which include organophosphates, carbamates and synthetic pyrethroids, however, do retain the risk that mosquitoes will become cross resistant to other classes of insecticides.

A barrier to introducing new insecticides is that the cost of procuring and using them is increased, and given the limited budget that the malaria control programme faces, there is a limited scope for introducing new insecticides. In addition, the development of new insecticides is largely done for the agricultural market, as the public health market is not sufficiently large to warrant new investment. Added to this is the strict and increasingly onerous international legislation that has made the development of a new class of insecticides vastly more expensive than it would have been several decades ago.

Along with the prohibitively expensive and difficult regulatory regime, is a growing acceptance of the precautionary principle within international environmental agreements and by regulatory authorities. This principle is loosely defined, but in essence gives regulators enormous powers to suspend or outlaw new technologies if they feel that adverse effects might arise. While this may seem sensible on the face of it, the principle can stifle new and much needed innovation. In addition, it does not take into account the risks of not having new technologies, as clearly seen with malaria control, and only assesses the potential risk of the new technology. The principle also ignores the fact that on balance, new technologies have always brought more benefits than harms.

Many of the problems that seemed to have beset the Malaria Eradication Programme during the 1960s and 70s persist to this day. Ensuring that the spray teams are motivated and conduct their spraying activities correctly is difficult, particularly as many of the sprayers are migrant workers and are only employed on a temporary basis.

In general, there appears to be a lack of accountability within the malaria control programme, where the spray men are unaccountable to the local population and there is a lack of effective management control. Reports that DDT destined for use in malaria control finds its way into the agricultural market is but one symptom of the lack of accountability.

Moving to a system where the sprayers and other malaria control staff are permanently employed and have some sort of performance-based pay structure could be a far more effective way of ensuring that the teams perform their functions better.

As will be explored in more detail below, the way in which the anti-malaria programmes are funded creates certain problems, especially for smaller states. The National Malaria Eradication Programme was a centrally-funded health programme until 1979, when the decision was made to split the funding equally between the national government and the states. The various states are now required to cover the operational costs of malaria control, while the central government undertakes to supply the required equipment and material. Seven of the north eastern states qualify for 100% of the funding, however certain states have difficulty in raising the 50% funding required for the control programme. This jeopardises the funding from central government and makes malaria control impossible.

Anti-DDT pressure

Numerous environmentalist groups oppose the use of DDT in malaria control on the grounds that it can lead to environmental damage. The attacks against DDT began with Rachel Carson's 'Silent Spring' which was first published in 1962. This well written book popularised the scare around DDT and claimed that its use was having widespread and devastating impacts on wildlife and human health.

The fears expressed in 'Silent Spring' were based upon the fact that DDT and its metabolites, DDD and DDE, accumulate in the body fat of animals. One of the most vociferous campaigners against the use of DDT has been the World Wide Fund for Nature (WWF). WWF takes the line that adverse health effects of DDT observed in laboratory animals point to potentially negative human health impacts. According to the WWF, DDT and its metabolites can interfere with various biological processes of the endocrine, immune, nervous and reproductive systems (WWF, 1998).

In addition, the WWF claims that DDT causes birth defects and egg shell thinning among birds and that it has brought several species to the brink of extinction. It is claimed by WWF that the estrogenic and anti-androgenic properties of DDT can lead to feminisation or demasculinization (WWF 1999).

Every year, new laboratory studies are published linking DDT to various deleterious effects among wildlife and humans. Yet to date, no scientific study has been able to replicate a case of actual human harm from DDT, despite over five decades of its use around the globe. DDT is classified as a possible human carcinogen by the US National Cancer Institute and has a lower carcinogen rating than coffee. Indeed there is no convincing evidence that DDT or its metabolites are carcinogenic to humans (Smith 2000).

No study has been able to link the use of DDT among sprayers with any negative human health impact. Indeed, the medical histories of employees at the Indian DDT production facility, Hindustan Insecticides Limited, have been tracked and show no cases of cancer associated with DDT. Most of these employees would have been handling and surrounded by

DDT most of their working life and yet they suffered no ill effect associated with the chemical.

The environmental impacts of the DDT use are also highly questionable. During the years in which DDT was widely used in agriculture in the United States, the bird population actually increased. The success of DDT in controlling insects ensured that vector-borne avian diseases were dramatically reduced. In addition, fewer plants were destroyed by insects, leaving more bird food available (Edwards, 1999).

The US Audubon Society conducts an annual bird count at Christmas time. During 1941 the number of robins recorded was 19,616 yet this increased to 928,639 in 1960 after several years of very heavy agricultural DDT usage (Edwards, 1999). There were birds whose population declined, particularly raptors, however most of the declines were recorded prior to the introduction of DDT. The bald eagle was threatened with extinction during the 1930s, mostly because it had been hunted, and even during the 1960s autopsies of bald eagles found that 71% of deaths were caused by gun shot wounds, electrification or by flying into buildings. Only four bald eagles out of the 76 autopsied were found to have died of disease and none of these was caused by insecticide poisoning (Edwards, 1999).

Despite the weak evidence relating to the negative human and environmental impacts of DDT, the public pressure that resulted from 'Silent Spring' and the anti-DDT movement prompted the US Environmental Protection Agency (EPA) to hold scientific hearings into the validity of the claims made against DDT in 1972.

From the outset, the EPA process was more political in nature than scientific. After seven months of hearings with evidence given by scientists both for and against the use of DDT, the presiding judge, Judge Edmund Sweeney, ruled that, based on the scientific evidence, there was no basis for a banning of DDT. This ruling was overturned by the head of the EPA, William Ruckelshaus, even though he didn't attend a single hour of the proceedings. Ruckelshaus argued that the pesticide was "… a warning that man may be exposing himself to a substance that may ultimately have a serious effect on his health."

The EPA had recently been formed and the banning of DDT was the first important task it undertook. It was important for the newly formed organisation to firmly show that it could take bold and decisive steps. The statements made by Charles Wurster, the chief scientist for the Environmental Defence Fund, an organisation chiefly behind the moves to ban DDT, support the view that it was important for the EPA and environmentalists to succeed in banning DDT, so that it would afford them greater powers to act in other areas. Wurster is quoted in the 'Seattle Times' of 5th October 1969 as saying "If the environmentalists win on DDT, they will achieve a level of authority they have never had before. In a sense, much more is at stake than DDT."

Indeed, prior to becoming the head of the EPA, William Ruckelshaus had supported the use of DDT in his position as assistant attorney general. In this position he stated that DDT had an "exemplary record of safe use" and that the claims of its carcinogenicity were "unproven speculation." A year later however, when addressing the Audubon Society, he said that he was deeply suspicious of DDT and that the EPA had streamlined policy and could suspend DDT at any time. He later said that as head of the EPA he was a maker of policy and not an advocate of the government, as he was when attorney general.

The political nature of the banning of DDT for agricultural use was subsequently confirmed when it appeared that much of the scientific basis for the ban contained in 'Silent Spring' was either wrong or exaggerated. The 1972 edition of 'Silent Spring' even testifies to this when on the back cover it states "No single book did more to awaken and alarm the world that Rachel Carson's 'Silent Spring'. It makes no difference that some of the fears she expressed ten years ago have proved groundless or that here and there she may have been wrong in detail."

The unscientific banning of DDT may have proved costly for farmers around the world, but there were alternative agricultural insecticides available. While most countries followed the lead of the US and banned DDT for agricultural use, the bans did not halt the use of DDT in disease control and public health use continued in parts of Africa, Latin America and Asia.

However, pressure was maintained by various environmentalist groups to ban the production and use of DDT completely. The most significant threat to the continued use of DDT in disease control came with the Stockholm Convention on Persistent Organic Pollutants.

The Stockholm Convention came out of a decision made in 1995 by the United Nations Environment Programme (UNEP) Governing Council (Decision 18/32, 25 May) to develop a legally binding instrument to control certain chemicals. The twelve chemicals that were initially targeted have become known as the dirty dozen and are considered to "pose major and increasing threats to human health and the environment".[11]

Of all these chemicals, DDT is certainly the most beneficial due to its role in malaria control, however the others play an important role in agriculture and certain production processes in the developing world. None of the chemicals are used by the industrialised nations, such as the US and Canada, that instrumental in driving the Stockholm Convention.

Five negotiating committee meetings were held between June 1998 and December 2000 where the final text of the Convention was negotiated and agreed. At the initial negotiating meetings it seemed as if DDT would be unconditionally banned and this was a position supported at the time by environmental groups, such as WWF.

The countries that still rely on DDT for disease control are mostly less developed and could not afford to match the large numbers of delegates sent by European countries or the United States. Usually, representatives from less developed countries could only afford to send one or two delegates to the negotiating committee meetings and almost invariably these delegates came from various departments of the environment. Some of the representatives were not even aware that DDT was being used in their countries for disease control as they had not been correctly briefed by their health department.

Despite these problems however, an exemption was secured for the use and production of DDT. DDT has been listed on Appendix B of the Stockholm Convention, as opposed to Appendix A which would have required complete elimination. Appendix B allows any country to seek exemption for either the production of use of DDT specifically for disease control. No other use of DDT is permissible and the UNEP, along with the WHO, reserve the right to reassess the necessity for DDT in disease control every three years.

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[11] http://irtpc.unep.ch/pops/indxhtms/gc1832en.html

The Stockholm Convention is yet to be ratified and therefore the DDT register does not exist. However, 29 countries have formally stated that they will be applying for DDT exemption if and when the Convention is ratified. Of these 29, only 3 countries, China, India and the Russian Federation, have been granted exemption to both produce and use DDT. A complete list of countries that have been granted rights to either use or produce DDT is given in Annexure A below.

Pressure to reduce the use of DDT still continues despite the exemption granted by the Stockholm Convention. In India such pressure is not limited to environmental groups such as Greenpeace and Toxics Link. Pressure has also been placed on the National Anti Malaria Programme by the Department of Trade and Industry (DTI) to reduce the use of DDT because of the potential impact on agricultural exports. It is argued that exports of agricultural produce to developed country markets could be jeopardised due to leakages of DDT from the public health sector to the agricultural sector.

The fact that DDT is banned in Europe and North America seems to legitimise the concerns of the DTI. However, banning the use of DDT will not help India to develop and will only ensure that the NAMP's already difficult task will be made more difficult. A far better solution would be to change the way in which DDT is procured and used so that leakages to the agricultural sector stop. At the same time, it would seem entirely legitimate for pressure to be exerted on developed countries to stop using unscientific and unfounded arguments as a trade barrier against cheap Indian agricultural exports.

Future Malaria Control Initiatives

One of the most serious challenges facing the malaria control programmes in India is the lack of effective new chemical insecticides. As has already been pointed out above, the Malaria Research Centre in New Delhi is currently testing a range of different insecticides that may be applicable. The problem with introducing new insecticides however is that there is not necessarily the budget to either purchase them or ensure that they are used properly. In some cases, new insecticides may be more costly and time consuming to spray, when compared with DDT, which is relatively easy to mix and use.

Bio-environmental controls remain a serious option in some cases. These methods include the removal of breeding grounds, the use of EPS polystyrene beads which can be spread across breeding grounds as larvicides, and the better management of engineering works so that new breeding grounds are minimised. In addition, larvivorous fish can be introduced in some areas where the vector breeds in large tracts of water or rivers and bacterial pesticides can be introduced[12].

The problem with bio-environmental control is that it is not always applicable in all areas. A careful assessment of the area, the local economy, ecosystem and type of vector is needed before any bio-environmental controls can be implemented.

For instance, a common problem with the introduction of larvivorous fish is that locals frequently catch the fish as a food source. This clearly undermines the control activities and they can be further damaged when the insecticide-treated bed nets are used as fishing nets.

[12] The Government of Kenya recently announced that it would be producing *Bacillus thuringiensis* for its vector control activities.

Educational projects can be of enormous value to communities in instructing them on how malaria is transmitted. A better understanding of the disease can lead to a greater personal responsibility in ensuring that people, particularly children and pregnant women are not bitten.

Stronger emphasis should be placed on finding new insecticides, ensuring that the existing insecticides are used better and that effective drugs are distributed and dispensed correctly.

Malaria and Climate Change

In recent years there has been a great deal of scientific and public debate on climate change and global warming (such as McMichael, 1993). Public health, particularly infectious diseases, has not escaped the global warming debate and it is a widely held view that global warming and climate change will deleteriously affect infectious diseases, such as malaria.

A simple internet search using the words ‘malaria’, ‘global warming’ and ‘climate change’ produces over 770 results. While these studies may be interesting and of some scientific value, they ignore the far more important fact that man’s activities have a far greater impact on the spread of malaria than climate (and certainly far more than the small part that man’s emissions may be playing in changing the climate).

The world is currently experiencing a general warming phase that began in the early part of the 18th century, and temperatures in the northern hemisphere are now similar to those experienced during the Middle Ages. There is a great deal of scientific speculation as to the causes of this warming trend. It is a popular view that man’s economic activities have contributed to the warming trend and some consider that this trend can be reversed. Although water vapour is the most significant greenhouse gas,[13] carbon dioxide (CO_2), which is generated in the burning of fossil fuels, is also a greenhouse gas and it is estimated that atmospheric concentration of CO_2 has increased from 0.029% in 1890 to 0.037% today.

There is a great deal of scientific debate concerning the extent of climate change, its potential consequences and man’s involvement in that change. The way in which climate change is measured is fraught with problems, as there are very few accurate measurements of historical temperatures, rainfall and other climatic data. It is not clear that the climate changes that are predicted will be entirely negative. It is clear that the proposed efforts to curb CO_2 and other greenhouse gasses will be extremely costly, and that these costs may prove to far outweigh the potential benefits, or may only be a fraction of the benefits – it’s simply unknowable. Any discussion therefore, on climate change should be undertaken with a great deal of scepticism, caution and awareness of the scientific debate.

Climate’s role in the spread of malaria may seem somewhat obvious. The spread of the disease relies upon sufficient numbers of Anopheline mosquitoes and a large enough parasite pool amongst humans and animals. The behaviour, development and population of mosquitoes are strongly influenced by climate. Temperature, rainfall, humidity all affect mosquito populations, as well as other climatic factors, such as wind and sunlight. The relationship between these climatic factors as they affect mosquitoes however, is highly complex and varies from country to country and between the different Anopheline species.

[13] The greenhouse gasses are implicated in causing global warming and climate change.

Increased rainfall and higher temperatures may provide more breeding pools for mosquitoes and can quicken the development of mosquito larvae into adults. However, where mosquitoes breed in large open pools or rivers, increased rainfall may flush out breeding sites and actually reduce the mosquito populations. In other areas where mosquitoes breed in small puddles or pools, increased rainfall may provide more breeding sites and therefore increase mosquito populations.

This complexity is well-illustrated by Reiter (2001) in his study of malaria epidemics in Sri Lanka. In the 1930s, epidemics were rare, but a steady rate of 1.5 million people (about a quarter of the population) were treated every year in malaria hospitals and dispensaries. In 1935, a catastrophic epidemic killed an estimated 100,000, largely from the south west, where the rainfall is high. This was unexpected, because the dominant vector, *An. culicifacies,* breeds along the banks of rivers and high water flow obliterates their breeding ground. In the drier parts of Sri Lanka, where epidemics were actually more common, fewer succumbed to this particular one.

The unravelling of the mystery shows the contrary nature of the relationship between malaria and climate. Two successive monsoons had failed, following five years of exceptionally favourable monsoons, which had led to high river flow and abundant rice crops. *An. culicifacies* became very rare in the southwest during the wet years. However, when the breeding grounds returned as rivers and irrigation ditches dried out after the monsoon failures, numbers increased enormously. In the intervening years, the population in the wet region was barely exposed to malaria, and the group immunity was low, making it extremely vulnerable to epidemic. By contrast, in the drier parts, where *An. culicifacies* continued its normal breeding patterns, immunity remained constant and that population was better protected against epidemic.

There are around 3,500 species of mosquitoes and they are found throughout the world, except in those areas that are permanently frozen. The success of mosquitoes is testament to their remarkable ability to develop strategies to cope with different climatic conditions. Mosquitoes are known to survive extreme cold and heat, for example, studies in Memphis, Tennessee revealed that mosquitoes were able to survive extremely cold winters with temperatures below -10ºC for more than 9 consecutive days. The mosquitoes managed to survive these temperatures by remaining in an underground storm water drain (Reiter, 2001).

In the Sudan, *An. gambiae* is able to survive where the outdoor summer temperatures can exceed 55ºC. The mosquitoes cope with these temperatures by remaining indoors and hiding in thatch buildings during the day and only emerging to feed after midnight. Clearly, while climatic factors play an important role in the transmission of malaria, their impact is highly complex and difficult to model.

By far the greatest impact upon the spread and incidence of malaria are man's economic activities and efforts to control the disease. While DDT finally eradicated malaria from Europe, the incidence of the disease had been declining since the late 19^{th} century. As Europe became wealthy and more developed, so the incidence of malaria declined. As the area of land under agricultural production increased, so the number of mosquito breeding pools declined. Improvements in agricultural technology meant that fewer manual labourers were required, which resulted in increased urban populations and reduced rural populations. By separating people and parasite pools from the malaria vector, the probability that the disease would spread was reduced. As households began to own more livestock, such as pigs and cattle, mosquitoes had a greater number of potential animals upon which to feed, this in turn reduces the probability that the malaria parasite will be transmitted. In addition, improved housing both separated farmers from their livestock and provided better protection from mosquito ingress.

Most of the reductions in the incidence of malaria occurred before Dr. Ronald Ross confirmed the link between the anopheles mosquito and the transmission of malaria. Indeed, targeted malaria control efforts were only implemented in the early 1900s, when the disease was already retreating in Europe.

While the incidence of malaria was declining during the late 19th and early 20th centuries, the disease continued to devastate large areas of Poland and the Soviet Union. While these areas were all subjected to similar, or even cooler, climatic conditions, the incidence of malaria was vastly different. Malaria epidemics were experienced throughout the 19th century and early 20th century in many parts of the Soviet Union. Outbreaks were not confined to the warmer climes around the Black Sea, but were experienced as far north as Archangel in the Arctic Circle.

While increased economic development, better housing, nutrition and sanitation led to decreases in most infectious disease in Europe, social upheaval and economic disruption in the Soviet Union and Poland entrenched and increased the incidence of malaria.

South Africa recently experienced a malaria epidemic, mostly concentrated in the northern Kwa-Zulu Natal province. The epidemic began after the South African Department of Health removed DDT from the vector control programme. The major vector, *An. arabiensis* is resistant to the synthetic pyrethroid alternatives that were introduced. In addition, *An. funestus*, one of the most efficient malaria vectors, returned to South Africa after an absence of around 40 years.

The epidemic also occurred during a period of above-average rainfall in KwaZulu Natal and indeed the whole of southern Africa. During 2000, DDT was reintroduced and because of parasite resistance to the drug combination sulphadoxine pyramithamine, a new artemisin based therapy was introduced. The result of these interventions was an 80% reduction in cases, even though the rainfall in 2000 and 2001 was lower than that for 2000, the South African Department of Health identifies DDT as the most important factor in the reduction of malaria cases (South African Weather Service, South African Department of Health).

The success of malaria control in South Africa was clearly far more dependant on vector control and medical interventions than on rainfall. Malaria, as with other infectious diseases in developing countries, is a major determinant of poverty, as will be discussed below. Policies, such as those proposed under the Kyoto Protocol that aim to limit CO_2 emissions and economic growth, will not materially affect the spread of infectious diseases but will hamper the abilities of poor countries to cope with health crises.

Conclusions and Recommendations:

The number of malaria cases in India is grossly underestimated by official studies and there could be more than 18 million malaria cases and around 130,000 malarial deaths every year.

The human and economic losses imposed by the disease are tremendous, yet successful control of the disease was achieved in the past and it is possible to decrease the number of cases with effective and well managed malaria control programmes. Without a number of changes to the malaria control programme however, the situation is unlikely to improve in the near future. We make a number of proposals below that could improve the effectiveness of the malaria control programme, improve prospects for development and ultimately save lives.

The generation, processing and dissemination of information

It is critical for malaria control programmes to have the correct scientific and clinical information on the malaria parasite and vector in order for their control to be effective. However, the way in which information is produced, by whom and how it is disseminated is not clear.

A number of restrictions are present in the current command-and-control mechanism of malaria control. For example, only insecticides that have been approved by the government and produced by government licensed manufacturers can be used. There is little incentive for these companies to produce and use the information as their market is guaranteed and not dependent on the efficacy of their product. In addition, government agencies like NAMP do not have any incentive to generate the information, as it is not their primary task. The result is that information remains scarce and results in efficiency losses and economic wastage of malaria control expenditure. For example, the last drug resistance survey was done in 1997 by the NAMP and subsequent drug policies are solely reliant upon this study.

In contrast, a situation where new participants, such as insecticide manufacturers or drug manufacturers are free to participate in malaria control, will create greater incentives to produce and disseminate information on product efficacy. It will also increase the incentive to ensure that resistance to these products does not occur and that they are used in the correct manner, for disease control and are not used in the agricultural sector. Independent academic reviews of these studies is important, however this could be sponsored by bodies such as the WHO.

Private practitioners, clinics and programmes have a greater incentive to acquire this knowledge in order to treat their patients better and add to their credibility. This in turn increases the market for the information and will increase the generation of sound scientific data.

The processing of information, in the existing framework is very slow. As discussed above, the NAMP's budget allocation is not aligned with the number of cases and the incidence of *P. falciparum* cases of states. This occurs because NAMP's information processing is slow and the information about incidences is compiled two to three years after the funds are actually spent. With greater decentralisation, this information could be processed much faster.

Currently, there is insufficient incentive for government agencies to disseminate the information. The little information that is generated is kept for their own use. With greater decentralisation and more accountability for regional malaria control teams that rely on information, it is more likely that this information will be disseminated more widely.

Decentralisation

It is a widely held view that private expenditure on malaria control will be insufficient and therefore a centralised programme for malaria control would be essential. It is also widely held that a centralised programme will bring regional equality in healthcare. But the slow moving nature of government means this programme is unresponsive to the changing nature of malaria control. Malaria control essentially requires area-specific solutions determined by area-specific information which national programmes frequently are unable to provide.

There is an urgent need to re-examine the assumptions behind centralized malaria control. Private expenditure on malaria control and treatment needs to be assessed more accurately. Giving individuals greater autonomy over the expenditure of malaria control funds may be a more effective method of reducing the incidence of malaria than under a highly centralised programme.

The aim of attainment of regional equality has proved to be disastrous (Draft national health policy 2001). In light of this, decentralization of malaria control programme seems an obvious solution. Local NGOs, local health associations, Gram-panchayats and housing societies, should all be empowered to undertake specific programmes of malaria control in their localities. Decentralisation will have a number of other advantages as well, such as in increasing people's awareness regarding the disease and increase their participation in malaria control.

Deregulation

It is increasingly clear that the Indian public health infrastructure is unable to cater for the needs of the population. The gap between demand and supply of health infrastructure is large and increasing, partly owing to a lack of private participation. The establishment of private clinics and hospitals is highly regulated and restricted, yet if these restrictions were removed, the increased involvement of the private sector could help in the effective control of malaria and indeed, of other diseases.

The development and production of insecticides and drugs for malaria prevention and treatment are also highly regulated. Restrictions on the use of some insecticides needs to be revised so that both state and private malaria control programmes have a greater choice in insecticides. This will increase their ability to curtail costs and manage the development of insecticide resistance. Many countries have onerous and excessive drug legislation that can increase the costs of drug development and delay their arrival on the market. Likewise, there is a great deal of scope to reduce this bureaucracy and ensure greater harmonisation with other countries in order to reduce the costs of drug registration.

Health surveys

A lack of a systematic and scientific health statistics database is a major deficiency in the present scenario. The health statistics collected are not the product of a rigorous methodology and the aggregation and analysis of data is not possible (draft health policy, 2001). Unreliable data as to the parasite prevalence and the extent of the disease hinders effective control strategies. For this reason regular and reliable data and health surveys are essential and could be funded by government, but conducted by private institutions or individuals

International pressure

The pressure exerted by developed countries and international environmental groups on India and on other developing countries to reduce the use of insecticides is significant. Once the Stockholm Convention on Persistent Organic Pollutants is ratified, it will either ban or restrict the use of twelve chemicals that are still widely used in the developing world. While DDT has been granted an exemption for use and production for disease control, its production, transport and trade are to be made more difficult and expensive. Bans or restrictions on DDT and, for example, HCH are neither in the interest of developing nor developed countries. If use of these insecticides is abandoned, the insecticide cover in the poor world will shrink, as the alternatives are far costlier. This will condemn India and other malarial countries to an increasing and ever more deadly presence of malaria.

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ANNEXURE A

Countries Requesting Exemption in Annex B of the Stockholm Convention on Persistent Organic Pollutants

Country	Specific Exemption or acceptable purpose
Algeria	Use of DDT for vector control according to part II of Annex B.
Bangladesh	Use of DDT for vector control..
Brazil	Use of DDT in production of dicofol (contained in dicofol as a contaminant).
Cameroon	Use of DDT for disease vector control in accordance with part II of Annex B and in line with WHO guidelines.
China	Production and use of DDT as an intermediate Production and use of DDT for disease vector control.
Comoros	Use of DDT for disease vector control in accordance with part II of Annex B.
Costa Rica	Use of DDT for disease vector control in accordance with part II of Annex B.
Côte d'Ivoire	Use of DDT for disease vector control in accordance with part II of Annex B and in line with WHO guidelines.
Ecuador	Use of DDT for disease vector control in accordance with part II of Annex B.
Eritrea	Use of DDT for disease control/public health services in accordance with WHO guidelines.
Ethiopia	Use of DDT for vector control for public health purposes in accordance with part II of Annex B.
India	Production of DDT for use in vector control and as an intermediate in the production of dicofol. Use of DDT for vector control and in production of dicofol (contained in dicofol as a contaminant (maximum concentration 0.1%))
Islamic Republic of Iran	Use of DDT for public health purposes in accordance with Who guidelines.
Kenya	Use of DDT in public health for vector control according to WHO guidelines.
Madagascar	Use of DDT for vector control according to part II of Annex B (date of expiry/review: 10 years)
Malawi	Use of DDT for malaria control.
Mauritius	Use of DDT for disease vector control I accordance with part II of Annex B.
Morocco	Use of DDT for vector control.
Mozambique	Use of DDT in the public health sector in accordance with WHO guidelines.
Papua New Guinea	Use of DDT for disease vector control in accordance with part II of Annex B

Russian Federation	Production of DT for disease vector control in accordance with part II of Annex B. Use of DDT for disease vector control in accordance with part II of Annex B.
Saudi Arabia	Use of DDT for vector control for public health purposes in line with WHO guidelines.
South Africa	User of DDT for disease vector control in accordance with part II of Annex B.
Sudan	Use of DDT for vector control in public health in line with the WHO guidelines.
Swaziland	Use of DDT in the public health sector for malaria control.
Togo	Use of DDT for vector control in line with WHO guidelines.
Uganda	Use of DDT for disease vector control/public health purposes in accordance with WHO guidelines.
United Republic of Tanzania	Use of DDT for public health protection.
Venezuela	Use of DDT for public health purposes in accordance with WHO guidelines.
Yemen	Use of DDT for vector control in line with the WHO guidelines.
Zambia	Use of DDT for disease vector control in accordance with part II of Annex B.
Zimbabwe	Use of DDT for disease vector control in accordance with part II of Annex B

Source: UNEP 2001b