Indian J Med Res 103, January 1996, pp 26-45

Re-emergence of malaria in India

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Accepted December 1, 1995

Malaria was nearly eradicated from India in the early 1960s but the disease has re-emerged as a major public health problem. Early set backs in malaria eradication coincided with DDT shortages. Later in the 1960s and 1970s malaria resurgence was the result of technical, financial and operational problems. In the late 1960s malaria cases in urban areas started to multiply, and upsurge of malaria was widespread. As a result in 1976, 6.45 million cases were recorded by the National Malaria Eradication Programme (NMEP), highest since resurgence. The implementation of urban malaria scheme (UMS) in 1971-72 and the modified plan of operation (MPO) in 1977 improved the malaria situation for 5-6 yr. Malaria cases were reduced to about 2 million. The impact was mainly on vivax malaria. Easy availability of drugs under the MPO prevented deaths due to malaria and reduced morbidity, a peculiar feature of malaria during the resurgence. The *Plasmodium falciparum* containment programme (PfCP) launched in 1977 to contain the spread of falciparum malaria reduced falciparum malaria in the areas where the containment programme was operated but its general spread could not be contained. *P. falciparum* showed a steady upward trend during the 1970s and thereafter. Rising trend of malaria was facilitated by developments in various sectors to improve the national economy under successive 5 year plans. Malaria at one time a rural disease, diversified under the pressure of developments into various ecotypes. These ecotypes have been identified as forest malaria, urban malaria, rural malaria, industrial malaria, border malaria and migration malaria, the latter cutting across boundaries of various epidemiological types. Further, malaria in the 1990s has returned with new features not witnessed during the pre-eradication days. These are the vector resistance to insecticide(s); pronounced exophilic vector behaviour; extensive vector breeding grounds created principally by the water resource development projects, urbanization and industrialization; change in parasite formula in favour of *P. falciparum;* resistance in *P. falciparum* to chloroquine and other anti-malarial drugs; and human resistance to chemical control of vectors. Malaria control has become a complex enterprise, and its management requires decentralization and approaches based on local transmission involving multi-sectoral action and community participation.

Key words Ecotypes-malaria-paradigms-reemergence-resurgence

India is endemic for malaria except for some healthy areas in the mountainous region above the 1800 msl and well drained coastal areas along the western and eastern ghats. In the island territories, while the Lakshadweep islands are free of malaria, in the Andaman and Nicobar Islands malaria is confined to the coastal areas only. Before the DDT era, malaria was responsible for an estimated 75 million new cases and 0.8 million deaths in normal years; these increased during epidemics. DDT spraying undertaken by several states between 1946-53 produced instant success in malaria control. Therefore, to control malaria an organized National Malaria Control Programme (NMCP) was launched in 1953. As a

result of DDT spraying under NMCP, 166 million population was protected from malaria, and by the end of 1957-58 there was 63-79 per cent reduction in epidemiological indices[1]. The progress of malaria control was so spectacular that, in 1958 NMCP was re-designated as the National Malaria Eradication Programme (NMEP), with malaria eradication as the final goal to be achieved in a phased time schedule of 7 to 9 yr[2]. In those days, malaria eradication seemed imminent and in 1965 out of 466 million population, malaria was wiped out in 373 million population (170 million population was in maintenance phase and 203 million population in consolidation phase), and only 93 million population remained in the attack phase. More areas were transferred into the maintenance phase in the following years, and by 1968 malaria eradication was achieved in 296 million population *i.e.*, 56 per cent of the country's population was brought under maintenance phase; 157 million population was in consolidation and 50 million in attack phase[3]. Further, deaths due to malaria were completely eliminated. These were the days of highest achievements under NMEP.

Euphoria of success was so overwhelming that malaria was considered a disease of the past and all work on malaria was de-emphasized, and what follows is the saga of malaria re-emergence. The epidemiological profile of malaria in the country is shown in Fig. 1. In 1965 there were about 1,00,000 cases of malaria and these cases steadily multiplied and touched a peak of 6.45 million in 1976. Epidemic situations were widespread in the country and therefore, malaria eradication concept had to be abandoned. This led to the implementation of the revised malaria control strategy. To combat malaria the Government of India in 1977 implemented the modified plan of operation (MPO). MPO was a 3 pronged strategy to attack malaria through; (*i*) government efforts; (*ii*) community participation; and (*iii*) operational field research. Under the MPO all sections with 2 or more Annual Parasite Incidence (API) were to be sprayed to interrupt transmission; and reduction in morbidity and mortality was to be achieved by drug distribution organized through the primary health care system and voluntary services by opening drug distribution centres (DDCs) and fever treatment depots (FTDs) throughout the length and breadth of India[4]. MPO reduced malaria cases to about 2 million by 1985, and malaria cases later stabilized at that level (range 1.8 to 2.2 million)[2,4]. There was no further improvement in malaria situation, instead malaria control was confronted with more problems. In the 1980s and 1990s malaria has become rather refractory to insecticidal spraying and a complex enterprise; and many factors have come together to create this situation[5]. Malaria transmission occurs due to the presence of man, mosquito and parasite, in a given environment[6]. In this paper an attempt has been made to highlight some of the key factors which have contributed to the re-emergence of malaria, bringing malaria in the forefront again.

Set backs to the eradication programme

The reversion of unit areas in the early days of successful malaria control from the consolidation and maintenance phases to the attack phase is shown in Table I. As early as 1963 and 1964, focal outbreaks occurred in 2 million population in the consolidation phase. These outbreaks were tackled by routine remedial measures. In subsequent years the malaria situation further deteriorated *i.e.*, in 1965-66, 11.56 unit areas, in 1966-67, 16.66 unit areas and in 1967-68, 23.95 unit areas were reverted from consolidation to attack phase. A unit was an administrative entity intended to cover on an average 1.0 million population. As a result of population increase, the unit covered 1.3 million population. The geographical area allotted to a unit was expressed as 1.0, and parts expressed as proportions such as 0.5, 0.8 *etc.*, of the unit area. As an example the areas in persistent attack were geographically located in 96 units, but the total unit area was 39.38[7]. For the first time in 1968-69, 19.60 unit areas were reverted from maintenance to attack phase from Gujarat, Haryana, Madhya Pradesh, Punjab, Uttar Pradesh and Rajasthan. It may be noted that by 1968-69, out of 71.385 operational units reverted to attack phase from the consolidation or maintenance phases, 41.60 units never moved out of the attack phase since the commencement of NMEP. These units were distributed over 20 states and union territories[8]. Thus the 1970 in depth evaluation concluded that while eradication was feasible in 91 per cent of the population living in previously malarious areas, there remains 9 per cent of the population (48 million) living in hard-core areas where attack operations continued for up

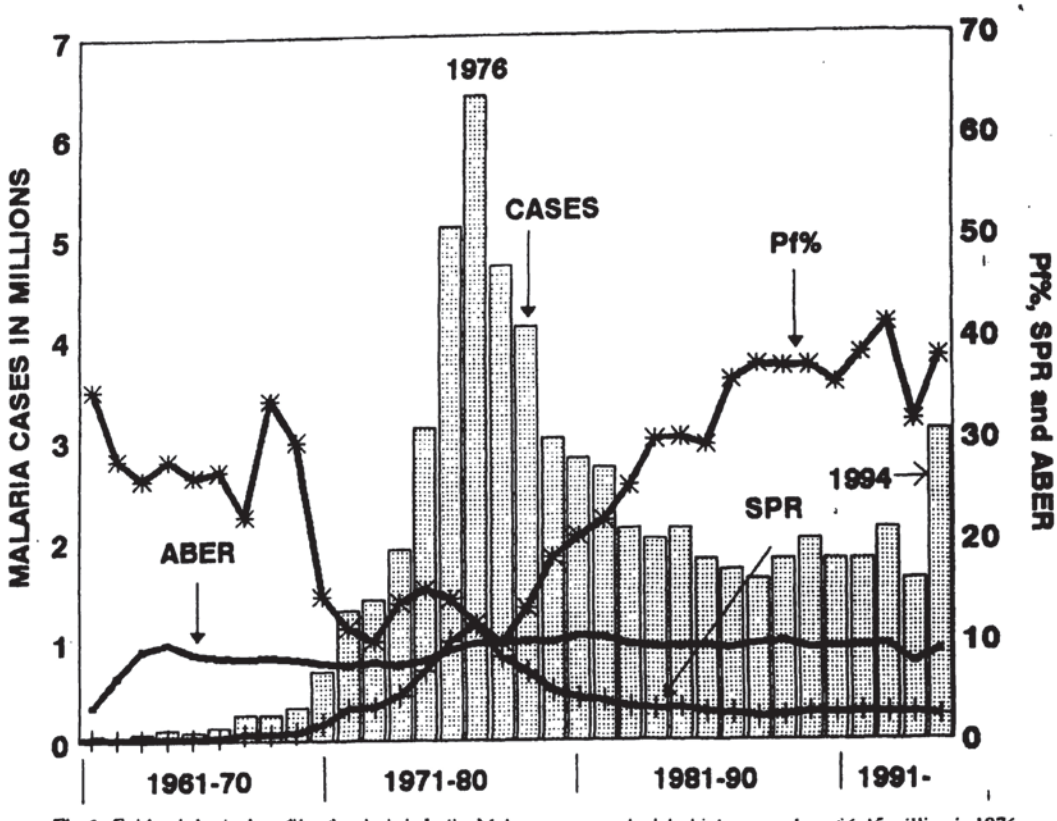

Fig. 1 : Epidemiological profile of malaria in India. Malaria cases reached the highest number of 6.45 million in 1976. Implementation of the modified plan of operation in 1977 reduced malaria cases but had no impact on *P. falciparum*. Annual blood examination rate (ABER) has remained at about the expected value of 10 (Source : NMEP).

to 12 yr[8]. The strategy of indoor residual spraying of DDT did not succeed in these areas and malaria foci were left all over the country.

The malaria incidence in India from 1961 through the period of resurgence is given in Table II. In 1964, overall API in the country was 0.00098. In the following years increase in the API was 200 to 300 fold, and malaria started to multiply in all areas under the maintenance, consolidation and attack phases. In 1966 and 1967, about 60 per cent of all cases were from areas under the consolidation and maintenance phases. Malaria resurgence was therefore considered irreversible and efforts to bring down cases and maintain the malaria free status in areas freed from the disease by re-phasing and the use of HCH and malathion did not succeed, and cases continued to rise till 1976 (Fig. 1).

An analysis of *inter-alia* key factors that contributed to the resurgence of malaria during the heydays of achievements revealed the following.

DDT shortages : DDT was the principal insecticide used in malaria control. Adequate quantity of DDT was supplied to the NMEP until 1962-63, through imports and indigenous production. As a result of DDT spraying, as much as 88 per cent of the area was in consolidation and maintenance phases, and only 12 per cent area (*i.e.*, 44 out of 393.25 units) remained in the attack phase. Successful malaria control was impeded by the irregular and interrupted supplies of DDT to the NMEP units (Table III).

Indigenous DDT production was about 30 per cent of the total requirement and its supply to the units was piecemeal during the eradication phase and even under the MPO. Imported DDT had to be purchased against hard currencies which were scarce. Therefore DDT shortages continued. For example in 1968-69 it was possible to make partial supplies of DDT to the states sufficient for the first round and not for the

Table I. Reversion of units from consolidation and maintenance phases to attack phases

S.no.	State	Consolidation phase				Maintenance phase
		1965-1966*	1966-1967*	1967-1968*	1968-1969*	
1.	Assam	-	-	-	1.57	-
2.	Bihar	0.25	0.25	-	2.625	-
3.	Gujarat	3.00	7.07	1.73	13.02	2.12
4.	Haryana	-	0.75	-	0.06	0.77
5.	Madhya Pradesh	3.00	4.00	11.75	15.24	2.00
6.	Maharashtra	0.25	0.25	3.19	6.19	-
7.	Mysore	0.95	0.95	0.90	-	-
8.	Orissa	1.00	1.00	0.20	0.20	-
9.	Punjab	0.75	1.64	-	0.25	1.62
10.	Uttar Pradesh	0.75	-	3.93	5.94	8.50
11.	Rajasthan	1.64	0.75	2.25	6.69	4.59
Total		11.54	16.66	23.95	51.785	19.60

*Temporary reversions made on *ad hoc* basis from consolidation phase during 1963 and 1964. Focal outbreaks occurred in consolidation phase areas involving a population of 2 million and were tackled by routine remedial measures (1)
Source : Madhok Committee (8)

second round. These shortages and interrupted supply of insecticides continued throughout the period of malaria resurgence. Malaria outbreaks initially recorded in the consolidation unit areas increased in numbers and outbreaks were also seen in the units in maintenance phase, thus more and more areas were brought under the attack phase.

Residual spraying : The details of spray rounds missed or extended since the commencement of the NMEP are shown in Table IV. Out of 96 units in the persistent attack phase, spray rounds were missed in 57 units and extended in 52 units. This was due to labour problems in 37 units, floods or heavy rainfall in 13 units and drought in 7 units. Delay and non-arrival of DDT was the main cause in 63 units (66%) associated with missed or extended rounds. The states most notably affected were Madhya Pradesh (15 out of 16), Gujarat (8 out of 9) and Orissa (8 out of 10). Thus the Madhok Committee* stated that 'The three factors working together *viz.* (*i*) late receipt of supply from USA; (*ii*) inadequate supply from indigenous sources; and (*iii*) short supply arising from inability to import timely additional requirement on the basis of actual phasing of the programme has been partly

Table II. Malaria incidence in India in different phases of the National Malaria Eradication Programme (NMEP)

Year	Attack phase		Consolidation phase		Maintenance phase		Total positive cases	API in maintenance areas	% increase in API over the previous year
	Nos positive	Total % of the positive	Nos positive	% of the total positive	Nos positive	% of the total positive			
1961	49151	100	-	-	-	-	49151	-	-
1962	54454	97.4	5121	8.6	-	-	59575	-	-
1963	73008	83.6	14308	16.4	-	-	87306	-	-
1964*	83664	74.1	29232	25.9	46	0.04	112942	0.00098	-
1965	68132	68.0	31492	31.4	561	0.6	100185	0.0033	236.73
1966	59306	40.0	85223	57.5	3627	2.5	148156	0.015	354.55
1967	121069	43.5	144719	51.9	12833	4.6	278621	0.05	233.33
1968	235759	85.8	22388	8.1	16734	6.1	274881	0.067	34.00
1969	299810	86.0	28829	8.3	20008	5.7	348647	0.076	13.43
1970	599809	86.3	50151	7.3	44687	6.4	694647	0.165	117.11
1971	1093250	82.6	86683	6.7	141184	10.7	1323118	0.452	173.94
1972	1084494	75.8	151093	10.6	194438	13.6	1430025	0.604	33.63
1973	1196724	61.8	343453	17.8	394308	20.4	1934485	1.224	102.65
1974	1778900	56.0	623803	19.7	770163	24.3	3172866	2.299	87.83
1975	2775856	53.7	939087	18.2	1451199	28.1	5166142	-	-

Source : Malaria in India through the years (9). Analysis of API in maintenance phase (personal communication, G.K. Sharma, NMEP)
*Surveillance commenced in 1964. API, Annual parasite incidence

Table III. DDT shortfalls in malaria control in India

Year	DDT (75% WP) in metric tonnes				Quantity %	
	Received		Short-fall			
	Required	Imported	Indigenous	Total		
1963-1964	18200	14627	3763	18390	0	-
1964-1965	14510	10815	3642	14457	0	-
1965-1966	14100	7390	2258	9648	4452	31.6
1966-1967	9350	3940	2728	6683	2682	28.9
1967-1968	8950	4060	3700	7760	1190	13.3
1968-1969	13148	8500	2933	11433	1715	13.1
1969-1970	15900	8535	4570	13105	2795	17.6
1970-1971	14806	5807	5407	11214	3592	24.3
1971-1972	14170	7000	4426	11426	2744	19.4
1972-1973	14170	5712	3666	9378	4792	33.8

Source : In depth evaluation 1970 (7); Madhok Committee (8).

responsible for a setback to the programme particularly since 1965-66'. Insecticide coverage to interrupt transmission was poor throughout the period of resurgence due to shortfalls and operational problems (Table III). Fig. 2 gives the estimated coverage of population based on insecticide consumed by the states (1977-84) against the target of 100 per cent. Spraying coverage was between 40-60 per cent under the MPO. A major problem was irregular flow of finances and shortage of matching grants (50 : 50 to be shared by the centre and state) at the state level[9,10].

General health services : Areas transferred from consolidation to maintenance phase had no active transmission, and the API was < 0.1 *i.e.*, 100 cases or less per million population. Malaria free status in areas under the maintenance was possible, if vigilance under the general health services was so well organized that all new cases of re-introduction or relapse

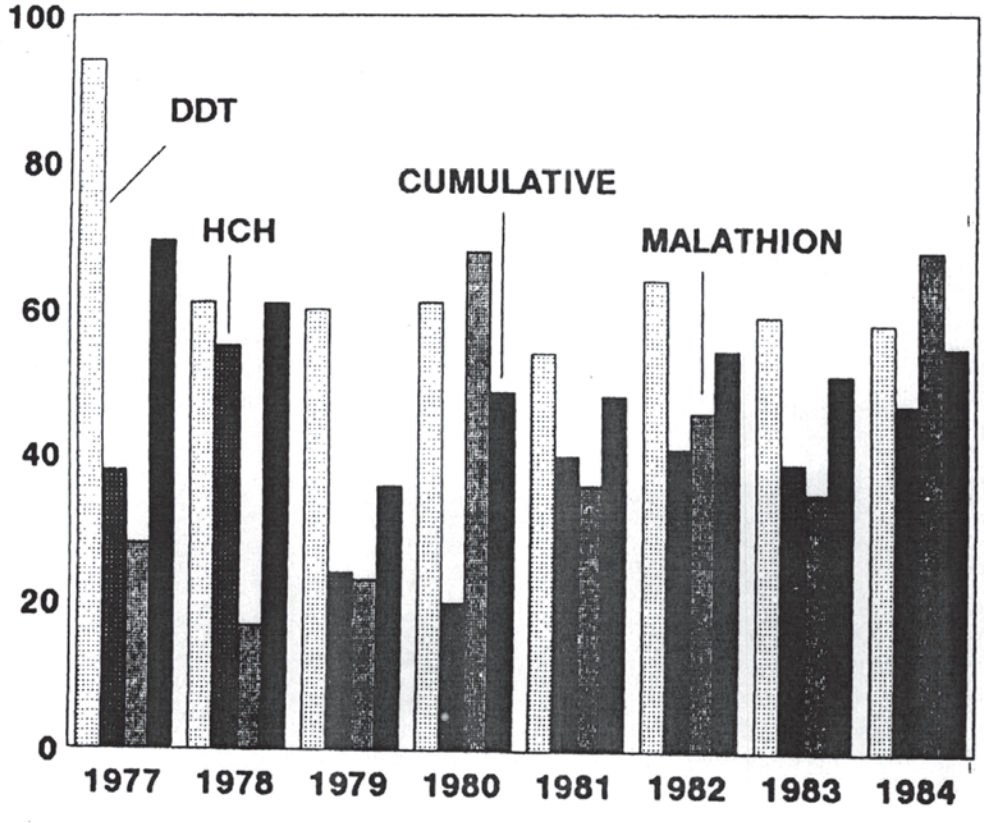

Fig. 2. Under the modified plan of operation sections with API 2 and more were to be sprayed with a suitable residual insecticide. Studies based on the amount of insecticide sprayed by the states revealed that the spray coverage varied from 40-60 per cent against the target of 100 per cent. Poor spray coverage could not interrupt transmission (Source : NMEP).

Table IV. Spray rounds missed or extended in time

State	Spray rounds reported as			Circumstance reported as associated with missed or extended rounds			
	Number of units	Missed	Extended	Labour problems	Floods or heavy rains	Drought or lack of water	Delay/non arrival of DDT
Gujarat	9	7	1	3	-	-	8 (89%)
Nagaland	1	1	-	-	-	-	- (0%)
Union Territories	6	2	3	2	1	1	2 (33%)
Orissa	10	7	8	7	-	2	8 (80%)
Uttar Pradesh	8	2	3	5	2	-	5 (63%)
Rajasthan	7	7	7	5	-	4	4 (57%)
Bihar	6	3	4	2	1	-	2 (33%)
Madhya Pradesh	16	16	9	3	-	-	15 (94%)
Assam	12	4	5	2	5	-	7 (58%)
Andhra Pradesh	9	4	3	4	2	-	5 (56%)
Maharashtra	6	2	5	4	-	-	4 (66%)
Mysore	1	-	-	-	-	-	- (0%)
West Bengal	4	2	4	-	2	-	3 (75%)
Jammu and Kashmir	1	-	-	-	-	-	- (0%)
Total	96	57	52	37	13	7	63 (66%)

*Considerable amount of data lacking. Missed since commencement of NMEP. Extended during 1967-69
Source : Indepth evaluation, 1970 (7).

would be promptly detected and treated. The malaria cases detected from 1964-67 in the maintenance phase of the programme, are shown in Table V. The annual blood examination rate (ABER) expected to be at least 10; was 0.4 in 1964, and 2.4 in 1965. Vigilance was the sheet anchor in preventing the re-establishment of malaria in areas freed from the disease. Studies revealed that surveillance was not fully developed to undertake vigilance during the maintenance phase. Health services were under-staffed, lacked motivation and supervision; and therefore performance in the field was tardy and deficient. Annual Parasite Index (API) in the maintenance phase in the early years increased several hundred fold and in 1975, 28.1 per cent cases were contributed from areas under the maintenance phase (Table II).

Delayed blood film examination prevented timely radical treatment. Laboratory services were unable to cope with the rise in fever cases, particularly during the transmission season. Backlog of slides for up to 4 months was common. Backlog of slides for 20

Table V. Malaria case detection during the maintenance phase

Year	Unit areas	Population in million	No. collected in			Annual blood examination rate		
			Active	Passive	Total	Active	Passive	Total
1964	58.76	68.75	0.13	0.17	0.30	0.27	0.36	0.4
1965	142.63	170	2.94	1.58	4.52	1.73	0.93	2.4
1966	196.25	237	6.34	3.25	9.59	2.67	1.37	4.5
1967	208.03	259	8.21	3.50	11.71	3.6	1.35	4.4

Source : Madhok Committee (8)

units in Gujarat was 2,11,702 on 30 September 1970, and for the 9 units under persistent attack phase, the number was 98,690. This contributed to the rise in malaria API in the consolidation and maintenance phases (Table II). This situation was commented upon by the 1970 indepth evaluation[7]. 'Therefore, the projection of units for entry into maintenance in areas where the health infrastructure was not adequately established or developed was the tactical error'. At that time it appeared as though the rural health services were well developed in Mysore and

Kerala, as the reversions had not occurred, and maintenance was kept under good control even in previously hyperendemic areas. Later studies in hyperendemic areas revealed that receptivity to malaria was completely lost due to ecological changes *e.g.*, in the Malnad foothill areas of the western ghats in the evergreen forest belt of Karnataka (formerly Mysore state). In this region indigenous people were chronic carriers of malaria and there was high mortality in the infants, pregnant women, and non-immune immigrants. *Anopheles fluviatilis* was the only vector which used to breed in slow running streams and maintained holoendemic malaria. DDT spraying provided an opportunity for exploitation of the region for economic betterment. Consequently this region was developed for coffee plantations and in the 1950s and 1960s vast forests were cleared for this purpose. As a result forest litter cover on the ground was slowly eliminated, reducing rain water percolation. Seepages from the hills gradually disappeared. Construction of minor dams at the base of valleys to trap water further eliminated streams where *An. fluviatilis* used to breed. All these developmental activities changed the ecology of Malnad. *An. fluviatilis* disappeared and along with it malaria. Today an area of 50,000 sq km is free of malaria[11].

Vector behaviour : In India there are 57 *Anopheles* species distributed unevenly all over the country. Not all Anopheles are vectors, and only six *Anopheles* are epidemiologically important. These are : *An. culicifacies, An. stephensi, An. fluviatilis, An. minimus, An. dirus* and *An. sundaicus*. History of malaria control in India is largely the history of *An. culicifacies* control. Other vectors are important locally. DDT spraying produced dramatic impact on these vectors. *i.e., An. minimus* disappeared, *An. sundaicus* was uprooted from the mainland, and now occurs in Andaman and Nicobar Islands. *An. fluviatilis* became epidemiologically unimportant in southwest and increased its influence in northeast India. *An. dirus* was limited to deep jungles, but also showed reduction due to deforestation[2]. The biology and ecology of these vectors profoundly affects malaria transmission. Some salient features of the behavioural dynamics of these vectors in relation to malaria re-emergence are given below.

Anopheles culicifacies was highly susceptible to DDT[12-14] but DDT resistance was first detected in 1959 in Gujarat[15,16]. Till 1966, DDT resistance did not interfere with the successful control of malaria, but in later years resistance posed problems in parts of Gujarat and Maharashtra[17,18]. Table VI gives the vectors of malaria in units under the persistent attack phase. Out of these unit areas, 39 units had spray operations for 13-17 yr and surveillance for 8-11 yr but malaria transmission control was unattainable. During 1965-69, a large numbers of operational units were reverted to spraying in states where DDT resistance was not the problem, as it was reported for *An. culicifacies* only (Table VI). In 1970, out of the 44 units scattered in 7 states, *An. culicifacies* was resistant to DDT in 35 units and to DDT and HCH in 5 units[19]. By 1974, resistance tests in *An. culicifacies* carried out in 11 states in 143 units revealed DDT resistance in 105 units and DDT plus HCH resistance in 20 units[20]. Initially resistance to DDT was high, the change over to HCH was effective but by 1970 malathion has to be introduced in units where DDT and HCH resistance was high. Although insecticide resistance was a problem but it was tackled by the use of replacement insecticides. It may be noted that during resurgence, focal outbreaks and localized epidemics preceded the evolution of resistance in the field. During 1960s, success in malaria control dampened interest in malaria research. The Malaria Institute of India (MII) switched over to other communicable diseases, notably small pox eradication programme and MII was re-named the National Institute of Communicable Diseases. There was therefore no research support to the NMEP when technical problems in malaria control started to emerge, one after another. This gap in research was filled up after resurgence had occurred. It was shown that *An. culicifacies* the major rural vector of malaria in India comprises 4 sibling species[21-23]. Natural occurrence of these sibling species regulates the transmission of malaria in rural and peri-urban areas[21,24]. Evolution of resistance to residual insecticides is also a characteristic feature of each sibling species *e.g.*, resistance to DDT in species B builds up early in sympatric populations of species A (vector) and B (non-vector). In such areas spraying of DDT produces epidemiological impact on transmission, although it may not be apparent by monitoring of the adult populations[25,26]. Similarly malathion resistance in species A

Table VI. Malaria vectors in units under persistent attack phase

S.No.	Vector Lp.	Seasonal	Perennial	Total
1.	*Anopheles culicifacies*	8	3	11
2.	*An. culicifacies* and *An. fluviatilis*	21	28	49
3.	*An. culicifacies*, *An. stephensi* and *An. philippinensis*	8	2	10
4.	*An. minimus*	0	14	14
5.	*An. minimus*, *An. balabacensis* and *An. philippinensis*	0	5	5
6.	*An. minimus*, *An. fluviatilis* and *An. culicifacies*	0	1	1
7.	*An. annularis*	1	1	2
8.	*An. annularis* and *An. fluviatilis*	1	2	3
9.	*An. sundaicus*	0	1	1
Total		39	57	96

Source : In depth evaluation 1970 (7)

takes a long time to precipitate as against species C (vector), which becomes rapidly resistant to malathion even in areas where malathion has not been used in public health, perhaps due to the use of organophosphorus compounds in agriculture[24,27]. This information was required by NMEP for targeted spraying to control *An. culicifacies*, but was lacking. There was no evidence of resistance in other important vectors like *An. minimus*, *An. fluviatilis*, *An. balabacensis* (= dirus), *An. philippinensis* (= nivipes) and *An. sundaicus*[28-30] and malaria resurged with equal vengeance in these areas. In northeastern states resurgence was linked with exophily and exophagic vector behaviour[1,19]. Resurgence of malaria could not be contained mainly because of the want of insecticides, refractory nature of vectors and exophilic vector behaviour compounded by the lack of understanding of the sociological and human ecological factors.

Urban malaria : *An. stephensi* is a well established vector of urban malaria and has been repeatedly incriminated from metropolitan towns or in urban areas of the country where piped water supply has been installed *e.g.*, Bombay[11], Delhi[12], Bangalore[33], Pune[34], Lucknow[35] and a few more. Although at that time of launching of the NMCP/NMEP, there were malaria cases in towns, the problem of rural malaria in India was so pronounced that at the time of planning of malaria control in the country, urban malaria was

Table VII. Diagnosed cases of urban and rural malaria in Gujarat

Year	Urban cases	Rural cases	Total	Urban cases (%)
1968	8,956	47,013	55,969	16.0
1969	11,461	80,878	92,339	12.5
1970*	22,214	68,782	90,996	24.3

Source : In depth evaluation 1970 (7); * Till September

considered insignificant. Most towns had no malaria as *An. stephensi* breeding sites were limited to wells and lacked piped water supply. The control of occasional rise in malaria cases was assigned to the municipalities/corporations. Therefore NMCP launched in 1953 and NMEP launched in 1958 were rural programmes. In 1961, there were 310 cities and towns with a population of 79 million which steadily increased to 100 million by 1967. Municipal/corporations were often under-staffed, inadequately financed and most importantly lacked technical expertise in malaria control[36]. Malaria control in urban areas required careful study and intensive larval control based on the 'species sanitation' approach developed by Covell[37] which were lacking. A study in Cambay city, Gujarat state in 1969 showed that *An. stephensi* was breeding in 613 well defined places like used and unused wells, cisterns and overhead tanks; but there were 9514 (15 times more) smaller breeding sites. Similarly towns in Andhra Pradesh showed that in some localities *An. stephensi* breeding potential was so high that with weekly anti-larval measures, 80 per cent of the time overhead tanks were positive with the first and second instar larvae[7]. There was active transmission in urban areas whereas transmission was being interrupted in rural areas, it remained uninterrupted in cities resulting in severe outbreaks of malaria in 1961 and 1962 in certain major towns of Andhra Pradesh and Madras. In 1963, out of 87,306 confirmed malaria cases 9,750 (11.2%) cases were reported from 10 municipal towns in Andhra Pradesh and Madras. Malaria cases in *An. stephensi* areas in the country increased from 7,475 in 1969 to 25,306 in 1970. The biggest increase was in Vadodara (Gujarat) from 83 to 11,113 followed by Ahmedabad from 3092 to 12,812. In Gujarat all the urban localities had malaria and a comparison of cases diagnosed in urban vs. rural areas for the 3 yr period showed considerable increase in urban ma-

laria cases[7] (Table VII).

The malaria incidence in urban areas of Tamil Nadu as compared to the total cases recorded in the state are given in Table VIII. During the period when malaria eradication was at its peak of achievement (1963-67), urban malaria accounted for > 90 per cent cases. Most of the cases were indigenous, and epidemiological investigations revealed that even the imported cases (25-30%) came from other towns with an urban malaria problem[38]. New malaria foci were being established in urban areas due to labour movement engaged in developmental projects in Andhra Pradesh, Gujarat, Maharashtra, Rajasthan and Tamil Nadu. These foci were disseminated into rural areas, and it was estimated that 25 per cent of the total cases detected were exported to rural areas[7,38]. Way back in 1948 the Bhore Committee[39] had said, much of the malaria in the country is man-made. In many cases, roads, railways and irrigation projects have a sinister account to their credit, through embankments having caused conditions of water logging favourable to the breeding of mosquitoes'. Thus, the 1970 indepth evaluation stated that the exclusion of urban malaria from NMEP was the most important omission in the eradication programme.

Table VIII. Malaria cases recorded in urban areas of Tamil Nadu as compared to total cases recorded in the state

Year	Total malaria cases in Tamil Nadu	Cases from urban areas only	Per cent
1961	1674	841	50.2
1962	1414	919	64.9
1963	3752	3555	94.7
1964	1596	1436	89.9
1965	594	543	91.4
1966	263	238	90.5
1967	183	161	87.9
1968	355	174	49.0
1969	761	252	33.1
1970	1099	975	88.7
1971	1550	387	24.9
1972	1179	603	51.1
Total	14420	10084	69.9

Source : Roy *et al.* (38)

Modified plan of operation

Rural malaria : Malaria resurgence had already occurred in the 1970s (Fig. 1). As stated before, in 1977, the modified plan of operation (MPO) was implemented in the country to control rural malaria[3]. To strengthen MPO, the *P. falciparum* containment programme (PfCP) was launched in 1977 in the country with the help of Swedish International Development Agency (SIDA) and the World Health Organization (WHO)[40,41]. PfCP was initially launched in 28 districts in northeastern states and gradually expanded to cover more and more *P. falciparum* dominant areas in the country. By 1981, 110 districts with a population of 121 million were brought under the PfCP. The programme was re-phased in 1983 and covered 84 districts involving 98 million population. Analysis of the annual falciparum incidence (AfI) indicated that reduction in areas under the PfCP in 1984 as compared to 1981 was 21 per cent (from 4.76 to 3.74). However, there was increase of 6.9 per cent in AfI in the country in areas outside the PfCP[4] *i.e.*, from 0.87 to 0.99. The PfCP was finally wound up in 1990. *P. falciparum* is found throughout the country, although its occurrence is uneven. There has been no improvement in the malaria situation, instead *P. falciparum* cases have risen steadily in the last decade.

In as far as the problem of malaria in India is concerned, it is grossly under-estimated[42-44]. There were problems in the drug distribution and implementation of MPO was tardy[45]. Based on chloroquine consumption, estimated 10-15 fold under-reporting of malaria cases was estimated or approximately 20-30 million malaria episodes each year was more realistic figure[46]. Deaths due to malaria are also under-reported and have fluctuated between 200-500 and in 1994, 1,167 deaths were reported following the epidemics in western Rajasthan and eastern India[47,48]. Based on crude death rate and the percentage of deaths due to fever and malaria an estimated 73,795 deaths occurred due to malaria in 1989. Vital statistics of India also reported similar figures of deaths due to malaria *i.e.*, 1,37,846 deaths in 1985 and 75,285 in 1987[46].

Vector resistance : Resistance in *An. culicifacies* first appeared in 1959 in Gujarat[15], further spread and intensified[16-18]. As for example resistance to DDT is now common in 18 states and 286 districts, to HCH in 16 states and 233 districts and to malathion in 8 states and 71 districts. Spraying to control *An.*

culicifacies is therefore not fully productive. In the rural areas, *An. stephensi mysorensis* has developed resistance to DDT in 34 districts in 7 states and to HCH in 27 districts in 6 states. Resistance to malathion has been detected in 8 districts in 3 states[49,50].

Residual spraying of insecticides requires vector species to be endophilic and susceptible to insecticide. Vector behaviour in the deciduous wet and tropical rain forest zone showed partial exophilic behaviour *e.g.*, *An. culicifacies*, and *An. fluviatilis*,[51,52] or fully exophilic *e.g. An. dirus* and some populations of *An. minimus*[53,54] and *An. sundaicus*[55]. Spraying in these areas did not produce the desired impact on malaria transmission.

Agriculture : Agronomic practices have also contributed to technical obstacles in malaria control. Use of insecticides in agricultural crops *e.g.*, in Andhra Pradesh and Orissa has precipitated malathion resistance in *An. culicifacies* species C, although malathion was more sprayed in malaria control[27]. Rice agro-ecosystem encourages breeding of *An. culicifacies* in fallow fields, and also for 6-8 wk in rice fields and *An. fluviatilis* in the slow running streams[56,57]. Sugarcane cultivation raises sub-soil water and encourages *An. culicifacies* breeding. Spraying is not acceptable to farmers in areas with sericulture or apiculture because of the mortality among the non-target beneficial insects. Insecticide residues in tobacco, tea and other agricultural products also seriously jeopardize exports. In many tribal areas the frequent habit of mud plastering makes the spraying ineffective.

Economics : Malaria control costs are increasing to become a major impediment in the public health programmes (Table IX). In about a decade malaria control costs to cover 1 million population by DDT and HCH have increased 3-fold and for malathion 2-fold. This steep rise in the cost of insecticidal spraying is adversely affecting malaria control. The population to be protected by insecticidal spray in 1988 and 1991 is given in Table X. Due to financial constraints population under spray has been reduced by 200 million, although there was increased malaria transmission as reflected by both the total number of cases and those *Pf* positive. This has led to further rise in malaria cases. Spray coverage during 1992-94 was further reduced against the target population

Table IX. Comparative cost of spray operations with different insecticides under the NMEP

Year	DDT (50%) Cost in lakh	HCH (50%) Rupees to cover	Malathion (25%) 1 million population
1985-86	33.00	36.00	192.00
1988-89	41.60	43.28	234.14
1994-95	90.10	88.90	361.20

Source : NMEP and MRC

Table X. Population coverage targeted for spraying under NMEP

Year	Malaria cases Total + Pf cases		DDT	HCH	Malathion
			Population in millions		
1988	1854830	685407	228.88	119.93	23.08
1991	2123578	918349	115.75	41.44	15.13

Source : Annual reports, NMEP; *Pf* ; *Plasmodium falciparum*

Table XI. Population targeted under spray and spray coverage reported by the states

Insecticide	1992		1993		1994	
	Targeted	%Covered	Targeted	%Covered	Targeted	%Covered
DDT	118.06	53.36	104.34	39.10	106.43	37.54
HCH	42.29	47.08	39.42	58.62	40.19	69.02
Malathion	15.442	48.05	15.73	18.05	16.05	16.76
Total	175.77	49.37	159.49	41.85	162.67	43.27

Source : NMEP : Population figures are in millions

requiring protection as estimated by the NMEP. Table XI gives the spray coverage during 1992-94. Coverage of population under DDT has been reduced from 53-36 per cent to 37.54 per cent, under HCH it improved from 47.08 to 69.02 per cent but under malathion it decreased from 48.05 to 16.76 per cent. On an average spray coverage was 40 per cent, and this reduction in spraying as a permanent feature has produced a rapid deterioration in the malaria situation.

Urban malaria : *An. stephensi* type form is a major vector of urban malaria and its control relies on legislative measures and required the strategies developed by Covell[37]. To control malaria in the towns and cities of India, an urban malaria scheme (UMS) was launched in 1971-72. Towns with > 40,000 population and API 2 or more for 3 yr were brought under the UMS[58]. UMS was implemented in phases

starting from 28 towns and so far this programme has covered 131 towns. In India all towns have been electrified and provided with piped water supply. Water supply coverage by 1990 in the urban areas was 84.4 per cent to be raised to 96 per cent by 2000. Wells have been retained to fight drought conditions. Water is supplied for a few hours in a day, and in some towns it is supplied 2 or 3 times in a week. Therefore the daily water requirements have to be stored in every house almost all over the country. This changed ecology has an enormous potential for *An. stephensi* to multiply and spread malaria. In towns with < 40,000 population spraying was required, but residual spraying was difficult even in the rural areas[10]. Malaria control in the urban areas required species sanitation (sanitation measures which produce species specific control) to eliminate *An. stephensi*, instead anti-larval methods were directed to control *Culex* mosquitoes, and to some extent against *An. culicifacies* in peri-urban areas. Although use of larvivorous fish was a standard method of urban malaria control even the fish hatcheries were not maintained. Temephos is applied at weekly intervals in potable water to control *An. stephensi*, but this is seldom done even in towns under the UMS. Many municipalities have no provision of malaria control, and in others manpower is inadequate and supplies for vector control are short. Legislative measures for preventive vector breeding are not applied any where in the country except in Greater Bombay[59]. Therefore urban malaria control was neglected permitting malaria incidence to multiply in areas under the influence of *An. stephensi* joined by *An. culicifacies* in peri-urban areas. In urban areas there is no active surveillance and therefore slide positivity rate (SPR) in some selected localities can provide indication of the prevailing malaria situation. SPR (1991-93) has varied between 12 and 38 in Visakhapatnam (AP); Chaibasa (Bihar); Sambalpur (Orissa); Bharatpur (Rajasthan); Madras, Tuticorin, Erode, Dindigul (Tamil Nadu); Calcutta (West Bengal); Surat (Gujarat) to name a few and the problem of urban malaria is widespread in towns under the influence of *An. stephensi*[60].

It is common knowledge that in urban areas most patients go to the private sector where treatment is given on clinical diagnosis. Also primaquine the drug used to prevent relapses and neutralize crescents is not available except through the NMEP. In some areas the problem of drug resistance in *P. falciparum* has become acute *e.g.*, Surat city. In the private sector which handles the bulk of patients in the urban areas, some clinicians lack knowledge on the diagnosis and correct treatment of malaria. There is no continuing medical education and often cases are mis-diagnosed or mis-treated. Differential diagnosis based on clinical symptoms is also difficult and unreliable *e.g.*, dengue, malaria, meningitis *etc.*

The urban pull is another phenomenon which is creating malaria. In each town about 25-40 per cent of the population lives in peri-urban areas without proper water supply and drainage. Housing is also poor. Such areas in the 1930s and 1940s were few and isolated. In these areas another vector *An. culicifacies* also transmits malaria. Malaria control in these areas is difficult as neither can these shelters be properly sprayed nor can the water receptacles be properly treated with temephos. Rural water supply scheme has covered 74.2 per cent villages with a target of 100 per cent coverage by the year 2000. *An. stephensi* prevalence increases in villages along with the water supply. A survey of 100 villages in Kheda district (Gujarat) showed the presence of *An. stephensi* and *Aedes aegypti* in all villages[61].

Malaria parasite : *P. vivax* is the predominant species in India followed by *P. falciparum*. In the maintenance phase percentage of *P. vivax* cases was about 60 and increased to > 85 due to residual spraying which reduced vector longevity and prevented *P. falciparum* transmission. *P. falciparum* cases dwindled during the eradication days, the percentage of total malaria cases fluctuating between 10-15 per cent. Since the implementation of the MPO, the major reduction was in *P. vivax* incidence *i.e.*, from 5,713,502 in 1976 to 1,417,641 in 1983 and maintained at 1.4 million level till 1994. *P. falciparum* transmission did not respond to spraying in a similar manner, instead cases have been rising steadily, as revealed by epidemiological data *i.e.*, in 1977-82 *P. falciparum* cases were between 0.5 and 0.6 million; in 1983-90 between 0.6 and 0.7 million; and 1991 onwards 0.8 and 0.9 million cases. Insecticidal spraying had a poor impact on vector longevity maintaining persistent transmission in many pockets in the country. As a result in the 1980s and 1990s, the

percentage of *P. falciparum* cases has risen to about 40. Since *P. falciparum* occurrence is widespread, falciparum malaria may rise further under pressure of environmental changes.

In the early days of the NMEP, *P. vivax* and *P. falciparum* were sensitive to chloroquine, and an adult dose of 600 mg chloroquine was adequate to clear the parasite from the peripheral blood. However 15 mg primaquine for 5 days was used to prevent *P. vivax* relapses and 45 mg primaquine was given as gametocytocidal to neutralize crescents of *P. falciparum*. Studies have shown that while *P. vivax* is still sensitive to chloroquine, a 5 day radical treatment with primaquine is inadequate[62]. Also it was found that *P. vivax* in Delhi is a mixture of many strains in regard to short and long incubation period, relapsing pattern and response to primaquine (Adak *et al;* 1995 unpublished data), and therefore vivax malaria may also strike if the pressure on vector control is withdrawn.

It may be noted that the main concentration of *P. falciparum* was in the northeastern states and in all tribal belts in the forested regions of the country. As indicated there is a steady rise in the incidence of *P. falciparum* infection. While *P. falciparum* infection was rising, a focus of *P. falciparum* resistance to chloroquine was detected in 1973 in Karbi Anglong and Nowgong districts of Assam[63]. Drug resistant cases were detected in 20 PHCs in 6 states by 1977[4], and resistant *P. falciparum* strains further spread in subsequent years[64].

The rising trend of *Pf* resistance along with the rise in *P. falciparum* incidence is shown in Fig. 3. The problem of chloroquine resistance in *P. falciparum* is now widespread, engulfing more and more areas and heading towards multiple drug resistance. It has been observed from the field that resistant strains become prominent in hyper-endemic areas with intense *P. falciparum* transmission and in developmental projects, industrial areas and around

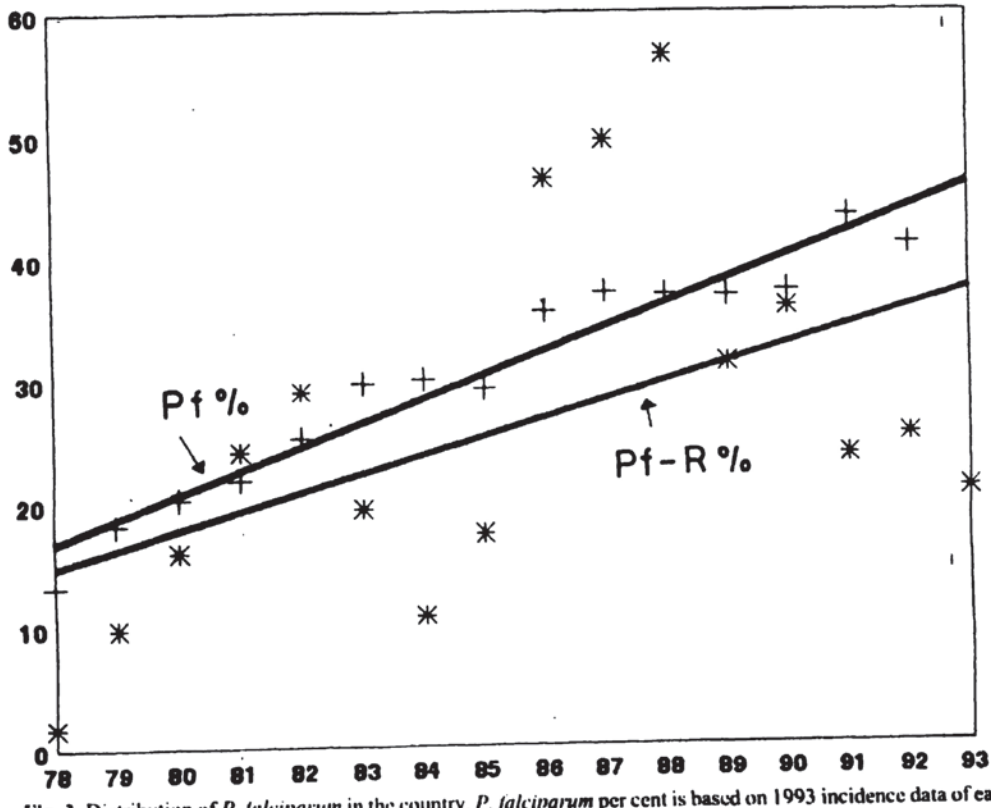

Fig. 3. Distribution of *P. falciparum* in the country. *P. falciparum* per cent is based on 1993 incidence data of each state. *P. falciparum* is distributed all over the country, although its proportion varies from state to state depending on the ecology of the region (Source : NMEP).

construction projects in urban areas. These projects attract labour from endemic areas with differential immune status leading to the accelerated transmission of resistant strains[65]. To treat RI level of resistance, amodiaquine instead of chloroquine was used in the NMEP but studies have shown no difference in the susceptibility status to either drug[66]. Resistance in *P. falciparum* to sulphalene pyrimethamine was first detected in Delhi in 1987[67]. Resistance has already emerged against sulpha-pyrimethamine, and quinine in northeastern states and Kolar district in Karnataka. Mefloquine resistance is found in Surat (Gujarat)[65]. This intrinsic characteristic of resistance in the parasite also provides a compromise with the host immunity leading to asymptomatic carriers. Population movement of carriers has become an important vehicle of parasite dissemination, seeding parasite in the non-immune populations and exposing them to the risk of acquiring malignant infection[68].

Human factor : Malaria is basically a disease of the poor and thrives in poverty. About 33 per cent of India's population lives below the poverty line, and this population is at a greater risk of contracting infection. Malaria treatment costs are also increasing, and WHO estimated that if the cost of treatment with chloroquine is one, it is 35-40 with quinine and antibiotics in the developing world. Therefore the poor suffer most as they contract malaria frequently and cannot afford proper and timely treatment and often become victims of the disease. An estimated 90 per cent of the malaria cases occur in Africa, south of Sahara, whereas out of the total expenditure on malaria control in the world, only 10 per cent is available to Africa. There are various factors of human ecology and behaviour that favour malaria transmission. Malaria is a focal disease, but *P. falciparum* predominates in the foot hills and in forests and forest fringes which are predominantly the tribal settlement areas. In the country 7.8 per cent tribal population contributes > 30 per cent of malaria, > 60 per cent *P. falciparum* and > 50 per cent deaths. Orissa alone contributes > 30 per cent *P. falciparum* cases[60]. Enhanced man mosquito contact is maintained by the poor housing, settlements near the mosquito breeding sites (*e.g.*, near rivers, streams *etc.*), poor clothing, exposure during work in the jungles particularly during nights, presence of highly efficient vectors *e.g.*, *An. dirus, An. minimus, An. fluviatilis* and high *An. culicifacies* densities in the plains. Vector behaviour and site of acquiring infection is not fully understood. Vectors are exophilic and exophagic maintaining extra-domiciliary transmission. These are the areas poorly served by the basic health services. Rural areas are served by 20,739 primary health centres. Tribal areas of the country with high *P. falciparum* incidence required 3,625 PHCs but so far 2,910 PHCs have been established and there is 31 per cent shortage of all categories of health personnel[65]. Cultural habits also impede field operations *e.g.*, habit of frequent mud plastering of walls, outdoor sleeping and use of local remedies to treat malaria *etc.*

Population migration has resulted in accelerated malaria transmission and in the introduction of new malaria parasite strains. Large scale population migration is a routine feature in the country for agriculture, projects, grazing, fishing and for exploitation of forest resources. In addition people also migrate during droughts, floods, political unrest, and nomadic tribes keep on moving from place to place. An estimated one sixth of the country's population moves annually during the transmission season from non-malarious to malarious areas and vice-versa. A large number of epidemics have been traced to migration in Orissa, Madhya Pradesh and south Bihar and Barmer in Rajasthan[4,10]. A study in northeastern states indicated that 46 projects employed 2,53,000 labour including 70,900 seasonal labour from outside these states. Malaria prevalence in this population was 11.1 per cent (7.1% *Pf* cases)[4].

Malaria in the 1990s

In India, malaria was mainly a rural problem. Two major patterns of malaria transmission existed in the country. These were the areas with (*i*) stable malaria with characteristic features of high mortality in forested and foot hill regions with pre-dominance of *P. falciparum;* and (*ii*) unstable malaria with focal transmission producing epidemics. In urban areas malaria cases were very few and did not require any intensified efforts.

Malaria control brought prosperity. There was overall development of the country. Vast areas that could not be colonized due to ravages of malaria

became the centres of the green revolution. Industrial growth was spectacular and made the country to emerge as an important competitor in the world market. Malaria was at such a low ebb that there was uninterrupted development of the hinterland, exploration of new areas, urbanization, and launching of new projects. Later these very development sites became the new paradigms of malaria as described below, in addition to the already well-known problem of rural malaria.

Urban malaria : In 1951 at the time of first census soon after independence the population of India living in 2590 towns was 62.44 million. The census in 1991 reported 217.18 million urban population, and towns had increased to 3768. The urban population is doubling in about two decades. In addition to the increase in urban population, there was an unprecedented increase in the expansion of urban agglomerations. Civic bodies are starved of funds and their infrastructure is so weak that they are unable to cope with the minimum needs of water, sanitation, and hygiene. Urban pull results in mushrooming of hutments and colonization of peri-urban lands unfit for settlements. This process threatens urban life due to pollution and outbreak of communicable diseases. Migration towards urban areas is a continuing process, and 25-40 per cent population lives in peri-urban areas. A marginal and insignificant problem of malaria in the urban areas has emerged as a distinct epidemiological type splitting into two ecotypes *viz.*, urban malaria transmitted by *An. stephensi* and peri-urban malaria transmitted by *An. stephensi* and *An. culicifacies*[10,69]. The total population involved is 150 million, an estimated 75 million in each ecotype. This problem is becoming more pronounced as could be seen by the rise of malaria in most urban areas under the influence of *An. stephensi*.

Rural malaria : The green revolution and exploitation of agricultural land by modern technologies has diversified rural malaria into rainfed areas affecting about 100 million population. Malaria is transmitted in these areas by *An. culicifacies* and dependent on rainfall. During the successive 5 year plans beginning from 1951, India's food production has increased from 52.5 to 182 metric tonnes in 1995 and during the same period to boost agricultural production irrigation has increased from 22.6 to 90 metric hectare (mha). This increase in irrigation has provided tremendous opportunities for malaria mosquitoes to breed uninterruptedly. Mosquito breeding occurs in seepages, poorly maintained irrigation system with weed growth, illegal irrigation, rise in water table creating marshy conditions and poor and inadequate drainage. Most of these conditions are commonly encountered in the irrigation projects and the command areas, and encourage *An. culicifacies* and in the slow running streams, *An. fluviatilis* breeding[70,71]. Irrigation malaria therefore has emerged as a new paradigm maintaining endemic malaria in about 200 million population living in the irrigation tracts.

Forest malaria : Epidemiological analysis of data from the endemic belts of the country has revealed high *P. falciparum* transmission in the forests of India, and these areas are dominated by the tribal population[72,73]. This population is also the most neglected segment of our society because of their life style, settlements in inaccessible areas, sociological structures and beliefs. Malaria control in these settlements has always been unattainable due to technical and operational problems[74]. These areas are hard-core areas with pronounced problem of vector refractoriness, in *An. culicifacies* and *An. fluviatilis* in peninsular India and *An. dirus*, *An. minimus* and *An. fluviatilis* in the eastern states. The other problems are high proportion of *P. falciparum*, high level of herd immunity resulting in asymptomatic carriers, and now a pronounced problem of drug resistance, and an unending source of malaria to the rest of the country. Because of the peculiarities in the transmission dynamics in the forests and difficulties in control operations compounded by technical obstacles, this type of malaria is known as forest malaria or tribal malaria, requiring specialized malaria control efforts[75]. Tribal malaria in the deep forests and forest fringe influences 50 million population and in the proximity of forest fringe areas with distributed ecology. In 1950 forest cover was 40.48 mha and this has been reduced to 22.3 mha in 1991. This massive deforestation has resulted in the introduction of new vectors in the forest fringes and distributed ecological belts (*e.g.*, invasion of *An. culicifacies;* and ecological succession of *An. dirus* to *An. minimus* to *An. fluviatilis*) affecting 20 million people, some of whom have started migrating for jobs to non-transmission areas with high malaria receptivity.

Industrial malaria : Industrialization has resulted in disturbance of the ecosystem encouraging active malaria transmission[76]. Unfortunately in the establishment of industrial belts, health impact assessment studies were not carried out and therefore industrial settlements invariably had come up in areas conducive to *An. culicifacies* proliferation and invasion by *An. stephensi;* and in the mining and forest based industries *An. fluviatilis*. In these areas malaria transmission is accelerated by a foci created by the tropical aggregation of labour. About 10 million population may be involved in industrial malaria, and because of the industrialization of almost all major cities of India, industrial malaria has emerged as an important ecotype with pronounced problems of resistance in *P. falciparum*.

Border malaria : Malaria at the international and state borders has always been a problem due to exchange of population, illegal activities in some areas, poor administrative control, inadequate and many times impractical malaria control operations, and difficulties in supervision. As a result populations living and working in these areas suffer from high levels of transmission. The problem areas comprise about a 16 km belt along the international borders. The most pronounced problem is along the Indo-Myanmar border followed by Indo-Bangladesh border, Indo-Bhutan border, Indo-Nepal border and Indo-Pakistan border. Major malaria vectors are *An. dirus, An. minimus* on the eastern side; *An. minimus, An. fluviatilis* and *An. annularis* in the northern borders and *An. stephensi* and *An. culicifacies* in the western border. There are vast areas under inter-state borders in the country where *An. culicifacies* is the vector. Border malaria therefore requires inter-country and inter-state understanding and collaboration in its control[77].

Migration malaria : Migration of population from endemic to non-endemic areas and vice-versa cuts across all types of malaria transmission patterns and involves multiple vectors. Migrants bring new parasite strains and continue to spread malaria wherever they settle. Migration malaria is becoming an important problem due to the pronounced problem of drug resistance in *P. falciparum*[10,78,79].

There are some relatively minor and local malaria ecotypes such as the coastal malaria maintained by *An. sundaicus* in the Andaman and Nicobar Islands. It may be noted that the above classification is a broad division of various ecotypes encountered in the country and in a given area one or more such ecotypes may be prevalent, as malaria is a local and focal problem.

In the early 1960s malaria was nearly eradicated and in 1965 there were about 100,000 cases in the entire country. Deaths due to malaria were completely eliminated. Thereafter technical, financial and operational factors[36] which were responsible for deterioration in malaria situation have only been aggravated with the passage of time. Thus the picture of malaria that has now emerged in the 1990s is summarized in Fig. 4. In the early 1960s NMEP was heading towards malaria eradication but during the same period reverses started in the consolidation and maintenance phases, and 71,385 operational units were reverted to the attack phase. NMEP faced technical problems which emerged, spread countrywide and consolidated making malaria control difficult and costly. The first problem was DDT resistance in *An. culicifacies* in the 1960 followed by resistance in *P. falciparum* to chloroquine in the 1970s. These problems increased in intensity along with the rise in *P. falciparum*. In 1980s malaria outbreaks were recorded from many endemic areas, although these areas were protected under the MPO. Deaths due to malaria became a regular feature. In the 1990s malaria epidemics have been witnessed in western Rajasthan, Manipur, Indo-Bhutan border and few more areas. At the turn of the century resistance in *P. vivax* to chloroquine and in *P. falciparum* to artemisinin derivatives may also emerge making malaria treatment still more costly and difficult. Epidemiological profile of malaria as seen in the 1990s reveals a progressive deterioration of the malaria situation in the country. Malaria transmission takes place by an interaction of man, vector and parasite under suitable environmental conditions (Fig. 5). In the last 4 decades or so the transmission dynamics of malaria have become more strong and intractable. Figure 5 (b) showed that re-emergence of malaria is characterized by the refractory nature of vector(s) either due to multiple insecticide resistance or exophilism or both; resistance in *P. falciparum* heading towards multiple drug resistance; resistance in man to allow spraying with many social and

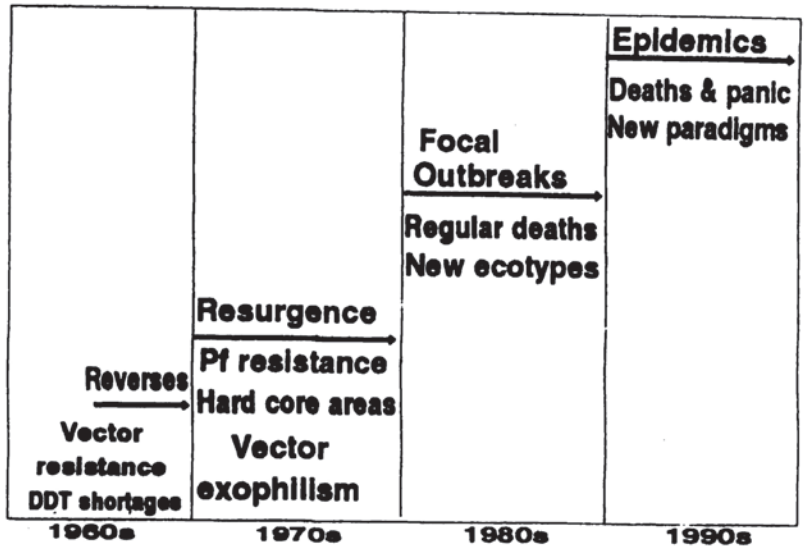

Fig. 4. Malaria trends over 4 decades. In early 1960s during successful eradication, vector resistance appeared and reversions of units to attack phase coincide with DDT shortages. In 1970s malaria resurgence was widespread; spraying did not control malaria in 9 per cent of the country's population identified as hard-core areas; resistance appeared in *P. falciparum*, and exophilic vector behaviour was pronounced. In 1980s focal outbreaks were recorded with regular malarial deaths and malaria started diversification into new ecotypes. In 1990s malaria epidemics are accompanied with death and panic, and there is clear demarcation of new malaria paradigms.

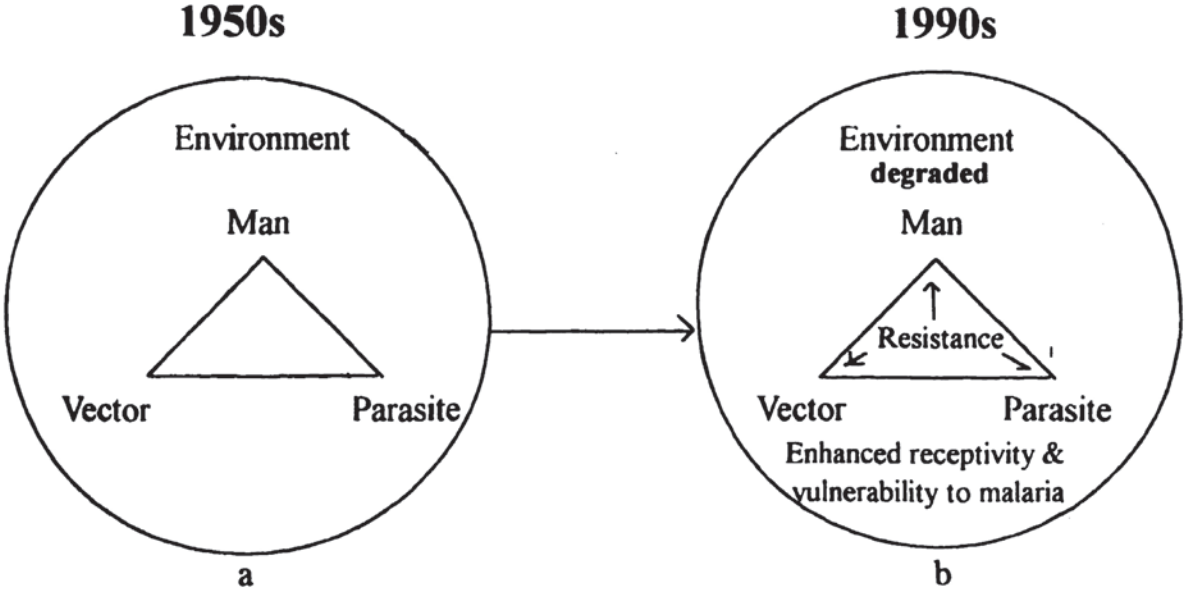

Fig. 5. Malaria triangle showing (a) vector, parasite and man interacting in a natural environment producing malaria, as was the case before launching of the NMCP/NMEP; and (b) in the 1990s malaria control is faced with the multiple problems (although variable in space and time) of vector resistance, parasite resistance and resistance in man to chemical interventions, behavioural and social problems. Aided and abetted by the environment which has become more receptive due to man made ecological changes. Malaria control therefore has become a formidable problem.

operational problems; and ecological changes favouring enhanced transmission due to creation of new and enormous vector breeding potential, and human behaviour enhancing man mosquito contact.

It is common knowledge that malaria vector tends to become refractory to chemical spraying and malaria transmission control requires a sound knowledge of vector biology to prevent vector breeding and reduce malaria receptivity and vulnerability. In recent years successful malaria control has been demonstrated by bioenvironmental methods[76,80-83], insecticide treated bed nets[84,85], minor engineering interventions[86] EPS beads[87,88], biolarvicides[89,90], repellents[91-93], use of diagnostics[94-95], chemotherapy[96], malaria vaccine[97], *etc.*, and old methods like fishes[98], have been revived. Furthermore, intersectoral coordination and community participation have been successfully elicited[99]. Approaches to malaria control should take into consideration local malaria transmission determinants and work with communities, integrating appropriate and local technologies, resources and talents.

Acknowledgment

I wish to express my gratitude to Dr S. Pattanayak and Dr G. K. Sharma retired Directors of NMEP, Dr R.S. Sharma, Director, NMEP, Shri N.L. Kalra, consultant, MRC, Dr V.S. Chauhan, Scientist, ICGEB, Dr S.K. Subbarao and Dr Lalitha Kabilan, Deputy Directors, MRC and Dr B.N. Nagpal, Senior Research Officer, MRC for reviewing the manuscript and for many constructive suggestions. This manuscript is largely based on the data generated by the NMEP Directorate and various reviews and evaluations set up by the Government of India from time to time. I acknowledge the use of this important data without which it was not possible to trace the events that led to the re-emergence of malaria.

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