COMMUNITY BASED BIOENVIRONMENTAL CONTROL OF MALARIA IN KHEDA DISTRICT, GUJARAT, INDIA

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ABSTRACT. A study on the bioenvironmental control of malaria was launched in 1983 in Nadiad taluka, Gujarat, with help of village communities. The implementation of strategy resulted in the successful control of larval mosquitoes and reduction in the adult vector populations, and the impact was visible in the curtailment of malaria transmission in large rural areas. When compared with the residual spraying of insecticides under the National Malaria Eradication Programme, the alternate strategy was found feasible, socially acceptable, cost effective and brought about environmental improvement and awareness in the rural areas.

INTRODUCTION

The strategy of intradomicilary application of residual insecticides to interrupt malaria transmission is beset with many problems such as insecticide resistance, operational failures, lack of collateral benefits, environmental contamination and high refusal rate to spraying. In some areas mud plastering soon after spraying and fear of adverse impact on cottage industries such as silk culture and beekeeping, exophilic vector behavior and the misuse of insecticides, etc. also create problems (Sharma et al. 1986).

The problem of malaria control is compounded by resistance of the *Plasmodium falciparum* parasite to aminoquinolines. It is perhaps possible to spray residual insecticides in malaria control for some years to come, but eventually the strategy would have to be curtailed because of social unacceptability and the high cost of insecticides. At present, the government of India is spending about 45% of the health budget (ca. US $57 million) annually on malaria control, and an additional equal amount is contributed by the state governments. There is therefore an urgency to search for alternatives to spraying that would not only tackle the many faceted technical problems but would also be environmentally safe and cost-effective. The alternate strategy known as the bioenvironmental control of malaria was conceived as a holistic approach to malaria control on a sustainable basis incorporating environmental improvement and in-income generating schemes (Sharma 1987). The purpose of this malaria control model was twofold; first, as and when the incidence of malaria would go down, people's interest in vector control would be sustained as part of the overall developmental process; and second, enhanced income of Panchayats (village councils) could be used in vector control, as also the improved economy would help fight the disease better. The field study was launched with the main objectives to: (1) demonstrate the impact of bioenvironmental vector control methods in malaria control, and (2) develop a cost-effective model for extension to other similar areas. Results of this study are reported in this paper.

MATERIALS AND METHODS

Study sites: The study was initially launched in July 1983 in 7 villages with a population of about 26,000 (designated as complex A) and one village was held as control. During 1983 sufficient ground work had been done to monitor the impact of antilarval and anti-parasitic measures beginning from 1984. In 1985 the experiment was gradually expanded to 14 more villages (designated as complex B, population 34,000), and during this period 3 villages were held as control. Until this time all the experimental and control villages were monitored to study the impact of intervention measures. The target area was expanded to cover the entire Nadiad taluka comprising an additional 79 villages (complex C) with a population of 290,000 in 1986. During the period, 5 villages in 5 surrounding talukas were held as control and impact of intervention was monitored in the 3 complexes of Nadiad using 10 indicator villages. During 1987 the study was further extended to cover Kapadwanj taluka comprising an additional 350,000 population. During 1987, 5 indicator villages were shifted from Nadiad to Kapadwanj taluka; thus, the total indicator villages remained at 10 although population coverage increased from 0.35 to 0.7 million (Fig. 1). At present the work is being consolidated before undertaking further expansion of the field work.

The Kheda district was selected because it was endemic for malaria with a high malaria incidence for several years as compared to other districts of Gujarat. The study villages in Nadiad taluka (subdivision of a district) had an extremely high malaria incidence in the preceding years with reports of deaths due to malaria. There was evidence of DDT, HCH and malathion resistance in the vector *Anopheles culicifacies* Giles. Although the areas were under reg-

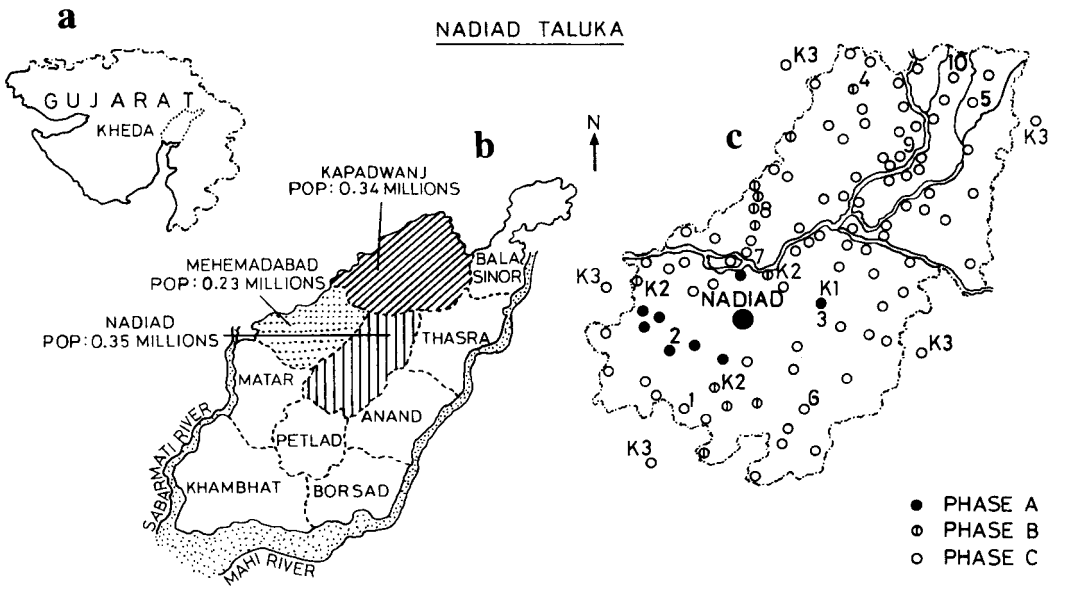

Fig. 1. Location of: (a) Kheda district in Gujarat, (b) Nadiad and Kapadwanj Taluka and the project extension to Mehemadabad Taluka, (c) complex A, B and C villages in Nadiad. Note: Control villages K1 1984, K2 1985, K3 1986–187. Monitoring was done in all villages of complex A in 1984, complex A and B in 1985 and villages 1–10 in 1986 and in 1987 in villages 1–5 in Nadiad and 6–10 in Kapadwanj.

Table 1. Composition of anophelines in the experimental villages.

	1984		1985		1986		1987	
Species[1]	Control (1)[2]	Experiment (7)	Control (3)	Experiment (21)	Control (5)	Experiment (10)	Control (5)	Experiment (10)
An. culicifacies	6.1%	4.14%	25.4%	4.4%	2.3%	1.53%	4.35%	2.54%
	(9.80)[3]		(87.78)		(4.76)		(11.76)	
An. stephensi	0.30%	0.15%	0.84%	0.12%	1.8%	0.41%	0.55%	1.09%
	(3.66)		(16.52)		(11.60)		(7.40)	
An. annularis	8.00%	4.96%	5.44%	3.25%	3.01%	0.66%	2.17%	1.35%
	(13.85)		(13.37)		(15.33)		(7.42)	
An. subpictus	84.51%	90.65%	67.90%	92.18%	92.73%	97.34%	92.87%	95.00%
	(17.89)		(84.71)		(18.21)		(10.62)	
Total no. checked	12,446	71,984	15,954	73,156	12,023	16,212	33,348	25,648

[1] Other anophelines were negligible. Above results are based on total mosquitoes collected during monitoring of populations.
[2] No. of villages are given in parentheses.
[3] z-values, significant at 1% level.

ular insecticidal spraying with HCH or malathion, people of the area suffered from repeated attacks of malaria. Initial surveys showed that some villages were located in low lying areas and there were innumerable larval mosquito habitats such as ponds, seepage water, intradomestic and peridomestic sites, drains, rivers, canals, wells, borrow pits, puddles, hoof prints and rain water pools, etc. The anopheline fauna consisted of 16 species, of which *An. culicifacies* and *An. stephensi* Liston, were the primary and *An. annularis* Van der Wulp, secondary vectors of malaria. In comparing the results of experimental areas with control, it was revealed that there was reduction in the proportion of vector populations at the expense of *An. subpictus* Grassi. This was found significant for each year (Table 1). Breeding of *An. stephensi* was restricted to intradomestic containers and wells whereas *An. culicifacies* had extensive breeding grounds. The most preferred breeding sites of *An. culicifacies* were rain water puddles, river bed borrow pits, irrigation channels, hoof prints, rice fields and other clean water collections. *Anopheles subpictus* breeds in almost every place such as all types of ponds, seepage water, wells and rice fields. At most places, mixed breeding was encountered in which *An. culicifacies* larvae were found in small numbers. *Anopheles stephensi* was found breeding in wells and the intradomestic containers. *Culex* breeding was mainly confined to stagnant polluted water, wells and ponds. *Anopheles subpictus* is not a vector (Rao 1984), but was the most prominent species and constituted about

90% of the anopheline fauna. In addition, *Culex quinquefasciatus* Say was commonly encountered in almost all types of waters. Adult mosquitoes densities were monitored by the suction tube method. For this purpose a 15 min collection was made from one room, and a total of 2 human and 2 mixed dwellings and 2 cattle sheds were searched in each village.

Intervention strategy and some results: The following antivector and antiparasitic measures were integrated to control malaria under the bioenvironmental control strategy.

1. Source reduction and larval control: Breeding in intradomestic containers was checked on a weekly basis, and containers found positive for breeding were emptied or destroyed. In water troughs used for washing clothes and also a source of drinking water for cattle, guppy fishes (*Poecilia reticulata*) were used, which almost completely controlled larval mosquitoes. Surveys showed that about 1–7% of the containers were found positive for mosquito breeding as against 7–29% in the control villages; statistical analysis showed a significant difference between percent breeding in control and experimental villages at the 1% level $t = 2.83$, which was taken as evidence for the effect of destruction in the preceeding weeks (Fig. 2). There was no adult emergence from the containers in the experimental villages since the larvae were destroyed on each survey. Of the total containers positive, *An. stephensi* breeding during 1986 and 1987 was 82% and 57% in experimental villages as against 94% and 86% in the control villages, respectively. Breeding in unused/abandoned wells was controlled by the application of 1–2kg expanded polystyrene (EPS) beads (R. C. Sharma et al. 1985). Wells treated with EPS beads have been negative for mosquito breeding for over 3 years, and EPS beads had to be applied again only when removed by villagers for irrigation due to drought. Villages of the Kheda district have a rural water supply. All leakages in taps, pipeline and tube wells, etc., were initially repaired by the project staff but maintained by the owners as a result of health education. Flowing water on the street which supported heavy *Culex* breeding was eliminated by promoting construction of soakage pits. So far about 2,000 soakage pits have been constructed which do not support any mosquito breeding. Major earthwork was carried out to fill and level low lying areas, borrow pits, depressions and roadside ditches which may hold waste water or rain water. Four tractors with hydraulic trollies for transporting earth are engaged in earthwork through village panchayats. The tractors, diesel fuel and driver belong to the Centre, but labor is supplied free by the village panchayats or individuals. Reclaimed land has been brought under cultivation, and eucalyptus trees have been planted in marshy areas because of their high water requirement. As a result some marshy areas have already become dry.

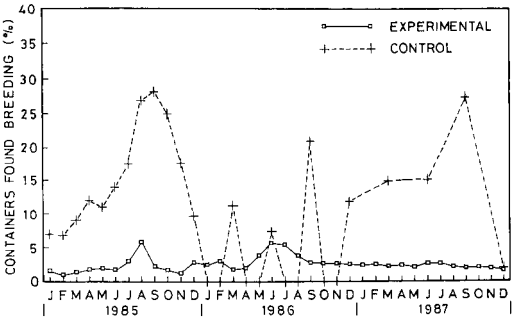

Fig. 2. Positivity of intradomestic containers for mosquito larvae.

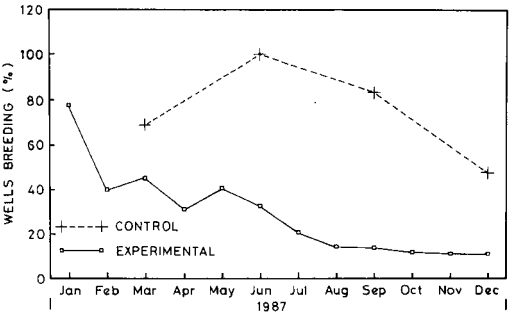

Fig. 3. Mosquito breeding positivity in wells with guppies.

2. Biological control: Surveys of the fish fauna of Nadiad taluka revealed that there were at least 27 species of indigenous fishes. Feeding tests showed that at least 14 species were larvivorous. The guppy, a native of South America, was introduced into India in 1908 (Jhingran 1985) for mosquito control. It was found in the wild and had the maximum potential as a biological control agent (Sharma et al. 1987). Guppy fishes are used extensively in all the experimental villages. In wells, guppy fishes (*Poecilia reticulata*) applied at 15–20 per well were used to control mosquito breeding. Surveys showed that during the year mosquito breeding positivity was reduced from 77 to 10% in the wells treated with guppies as against from 100 to 47% in the untreated wells in the control area (Fig. 3). For an effective control of breeding in the ponds, margins were kept clean to enable the fishes to feed upon the larvae on the edges. Guppies are being mass produced in the villages in a variety of ponds and cement tanks that otherwise would lie abandoned and provide mosquito breeding sites, particularly during and

after the rains. At present 94 hatcheries have been established by the project in the village ponds with an estimated stock of 20 million guppies. The fishes multiply in the ponds without any efforts or input at a negligible cost in way of supervision. All requirements for larvivorous fishes are met from these ponds.

3. Surveillance and treatment: Weekly surveillance was organized by the project staff to detect all parasite positive cases through house to house visits and antimalarials were administered based on recommendations from the National Malaria Eradication Programme (NMEP). Blood smears were prepared from fever cases and given 600 mg chloroquine as presumptive treatment. The slides were brought to the laboratory, stained and examined for the presence of malarial parasites. Results of slide examination were communicated within 48 h, and all parasite positive cases were given a radical treatment. This comprised an additional dose of 900 mg chloroquine in divided dosages and 45 mg primaquine (gametocytocidal) for *P. falciparum* and 75 mg primaquine (anti-relapse) at 15 mg/day for 5 days to *P. vivax* cases. Children were given proportionately lower dosages. *Plasmodium falciparum* recrudescences were administered 2 tablets of Metakelfin and 45 mg primaquine.

4. Health education and community participation: Peoples' participation through health education received maximum emphasis. In order to educate all sections of the village, community health camps were organized and interpersonal discussions were held in all villages, intervention measures were exhibited and demonstrations were arranged in schools and market places. Folders, charts, pamphlets and other health education material was prepared and distributed. In addition, Ahmedabad TV prepared at least 10 short video films, and these were periodically telecast. These activities produced tremendous positive responses from the communities. Female health visitors arranged special meetings on a routine basis to educate women, children and people of low socioeconomic status. As a result, large numbers of people participated in vector control work individually and in groups (known as Shram dan) to carry out major earthwork. Patients with fever started to approach our staff for blood examination. People who could not participate in our activities made cash donations for vector control, and so far Rs. 2.5 lakhs = US $17,000 has been received. Communities also participated in the social forestry program which consisted of planting trees in the waste land belonging to panchayats and also farm forestry under the decentralized nurseries scheme of the National Wasteland Development Board (NWDB) of the governnment of India, and other developmental and income generating schemes.

5. Environmental improvement and income generating schemes: During the intervention phase a dumping ground with borrow pits supporting heavy mosquito breeding was cleaned by motivating village youths and converted to a playground. In many areas *Eucalyptus* were planted to convert marshy areas into dry land. Waste land was used to promote social forestry with the objective to make the land productive and increase income of the panchayats. So far about 1 million saplings of all types including *Eucalyptus* (24.7%) were planted with the assistance of the panchayat and forestry department. In addition, decentralized nurseries funded by the NWDB were encouraged; and during 1987, 270,000 trees were donated for farm forestry. During the last 2 years about 3,000 improved chulhas (wood stoves) were installed, and other sources of alternate energy such as solar cookers and bio-gas plants were promoted to prevent deforestation. Ponds infested with water hyacinth support mosquito breeding on the margins since the dense weed cover does not support fish survival. Also the drying and receding ponds produced innumerable puddles protected by hyacinth. These inaccessible marshy areas become important *Culex* breeding sites, and there was no simple method to control mosquito breeding. Therefore, all ponds infested with water hyacinth were cleaned manually at a cost of about Rs. 70,000 (US $4,700). Panchayats shared the expenditure to the extent of about 40–60%. This has eliminated a major *Culex* production site and enriched the ecology. For the first time, flamingos were sighted in Nadiad taluka in almost all ponds. In addition, ponds of 3–5 ha were converted to the production of edible fishes like the Chinese and common carp on experimental basis; e.g., 4 ponds taken from the villages in complex-A produced fishes of Rs. 1.0 lakh (US $6,700) in 1986 and 1.7 lakhs (US $12,000) in 1987. Although carps are larvivorous in their juvenile stages, carp rearing was introduced primarily as a means to increase income of the panchayats. Money collected from the sale of fishes was diverted for vector control work by hiring labor for the earthwork, and in one village an underground sewer was laid.

6. Inter-agency cooperation: In the implementation of various programs, help and technical advice was solicited from various agencies working in the area, such as the departments of health, social forestry, irrigation and drainage, fisheries, Gujarat energy development and panchayats, etc. At present, all activities in the experimental areas are being carried out by the project staff. It is envisaged that as and when the program is implemented by the state govern-

ment, other departments would directly participate through a coordinating agency in preventive and corrective measures related to disease vector control.

RESULTS AND DISCUSSION

In India resurgence of malaria started in the late 1960s, and malaria cases increased from 0.1 million in 1965 to 6.5 million in 1976 (Sharma 1984). Reasons for this resurgence were identified as technical, financial and administrative (Sharma and Mehrotra 1982). Following resurgence, malaria outbreaks including deaths due to malaria have been reported from many areas (Sharma et al. 1984, 1985; Chandrahas and Sharma 1983, Ansari et al. 1984, Malhotra et al. 1985). One such area with outbreaks was a group of villages in Nadiad taluka, Kheda district, in which DDT and malathion were being sprayed to contain transmission (Sharma et al. 1986). There were no suitable replacement insecticides available at affordable prices that could be used in place of malathion; thus, this situation was unlikely to improve. As a result, our interest in the control of malaria by the biological and environmental management methods was reawakened. Even a cursory review of literature on this aspect of disease vector control shows innumerable examples of successful control by environmental management methods throughout the world, beginning from the classical work on malaria control by Sir Ronald Ross (1910). Other notable examples are malaria control in the USA in the Tennessee Valley (TVA 1947, Gartrell et al. 1981), in Malaysia (Field and Reid 1956) and Indonesia (Snellen 1987), and the control of dengue hemorrhagic fever in Singapore (Chan and Bos 1987). There are several examples of successful malaria control from the early days in India, viz., malaria control in Bombay (Vishwanathan 1950), antimalaria operations in irrigated areas by Clyde (1931) during the Sarda canal construction, malaria control in the Irwin canal project (Rao and Nassiruddin 1945) and the Cauveri-Mettur project (Russell and Knipe 1942). Other examples include control of rural malaria caused by *An. fluviatilis* James by de-weeding (Vishwanathan, 1946), growing shade-loving plants over the tea garden drains to control *An. minimus* Theobald (Covell 1955) and recent examples of malaria and filariasis control by Sharma (1987), Dua et al. (1988) and Rajagopalan et al. (1987). The implementation of bioenvironmental control methods, viz., vector control by the integration of biological control methods and environmental modification and management methods in Nadiad taluka of Kheda district produced encouraging results particularly at a time when insecticidal application was not producing the desired results. The impact of intervention measures was visible in the reduction of total water surface area inside the village and in the agricultural fields. Mosquito breeding in houses and peridomestic containers was almost completely eliminated. Well breeding was completely suppressed with the help of EPS beads, although some breeding was found in used wells treated with fishes. Breeding was however occasionally encountered in some permanent ponds along the shallow margins, but its intensity was greatly reduced in most areas. Together, these sites produced considerable mosquito populations, and therefore control of vector species was emphasized as far as possible. As a result, there was significant reduction in man-hour collections of *An. culicifacies* from 1984 to 1987 (Fig. 4), and *Anopheles stephensi* populations were reduced to very low numbers. The antilarval measures adopted also resulted in considerable reduction in the densities of other anophelines and *Culex* mosquitoes. *Anopheles subpictus* populations remained high throughout the year and the impact of minor engineering works on *An. subpictus* was visible only during the peak density period in September when the experimental villages had densities, e.g., 150 to 200 man-hour density (MHD) as against 300 to 400 MHD in the control villages. The difference was found to be statistically significant at the 10% level (t = 1.77, for 1987). This was mainly due to innumerable breeding sites available including the ricefields in which 80–97% of the immatures were comprised of *An. subpictus* and ca. 5% *An. culicifacies*.

Weekly active and passive surveillance was sponsored by the project since the inception of the study. Annual blood examination rate (ABER) varied from 30 to 45% in all the 3 complexes as against 10% usually targeted based on fortnight surveillance under the program (NMEP). Higher ABER in project area ensured

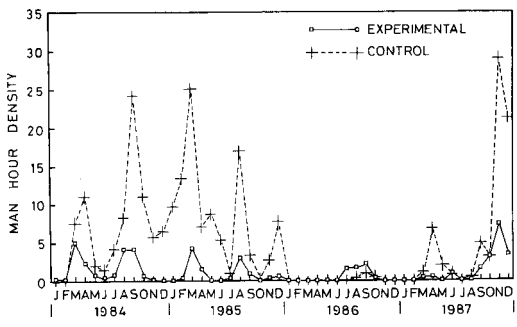

Fig. 4. Density of adult *Anopheles culicifacies* in human dwellings, Nadiad.

Table 2. Spray history and malaria cases (Kheda district).

	Nadiad taluka complex						Rural areas outside experimental villages of Kheda district	
	A		B		C			
Year	Spray history	+ive/Pf[1]	Spray history	+ive/Pf	Spray history	+ive/Pf	Spray history	+ive/Pf
1981	HCH/MAL	3,534/685	HCH/MAL	1,910/34	HCH/MAL	11,670/303	HCH/MAL	66,884/1,403
1982	HCH/MAL	2,080/93	HCH/MAL	2,022/8	HCH/MAL	11,271/131	HCH/MAL	51,460/869
1983	DDT/HCH	418/89	DDT/HCH	474/4	DDT/HCH	3,253/54	DDT/HCH	28,247/1,045
1984	BC	141/64	DDT/BHC/ MAL	137/39	DDT/BHC/ MAL	1,274/32	DDT/BHC/ MAL	16,422/635
1985	BC	68/28	BC	86/24	DDT/MAL	906/187	DDT/MAL	6,585/428
1986	BC	62/30	BC	68/16	BC	496/165	No spray	7,753/1,400
1987	BC	230/50	BC	177/56	BC	880/265	No spray	14,257/1,744

Source: NMEP.
BC, Bioenvironmental control.
[1] +ive/Pf—Total millions/*Plasmodium falciparum* cases.

detection of more malaria cases, although radical treatment alone in such areas has not brought down transmission to very low levels over the years. As an example, in Rameswaram island the ABER is generally between 50 to 60%; and it was 129% during the 1979 epidemic, but persistent transmission was maintained in the island in the successive years (Chandrahas et al. 1984). Table 2 gives the spray history and malaria cases in the experimental areas of Nadiad taluka and rural areas of the entire Kheda district. It should be pointed out that Kheda district had experienced an epidemic of malaria before the start of experiment; i.e., in Nadiad taluka there were 17,114 cases in 1981 and 15,373 cases in 1982. At that time, in Nadiad taluka some villages were sprayed with HCH and some with malathion. In subsequent years DDT was sprayed, and there was a considerable reduction in malaria cases. This reduced transmission was perhaps the combination of various factors such as the natural decline during the postepidemic period (in this region malaria peaks at an interval of 5 to 7 years) and may be perhaps due to better performance of DDT (susceptibility data are not available) as it was not sprayed for several years. In addition, poor surveillance may have masked some of the incidence. In areas where bioenvironmental control was implemented, the incidence of malaria was greatly reduced. When these data were compared with talukas outside the experimental areas, there was a parallel reduction in villages under DDT spray. Therefore, it may be concluded that the strategy of bioenvironmental vs. the spraying was comparable in its effectiveness during the declining or interepidemic period. This period may be 5 to 7 years or more, and its impact during epidemic or ascending malaria trends could not be ascertained as the epidemic situations are now building up for the first time since the start of the experiment. During 1987 there has been an increase in malaria cases in Nadiad taluka. Similar increase of a little higher magnitude was recorded in all the surrounding areas under insecticidal spraying. The slide positivity rate (SPR) of Nadiad and its 6 surrouding talukas (see location in Fig. 1) is given in Fig. 5. It may be noted that the district was under DDT and malathion spraying since at least 1961, but no spraying was done in 1986. In 1987 all rural areas were sprayed except the Nadiad and Kapadwanj experimental talukas. Kapadwanj taluka was included in the experimental area in 1987. The slide positivity rate in Nadiad showed a declining trend until 1986 and an increasing trend in 1987. This increase in SPR, if compared with neighboring talukas, revealed that in some insecticide-sprayed talukas the increase in SPR was significantly large as compared to Nadiad and Kapadwanj talukas. In other sprayed talukas the SPR remained similar to Nadiad or Kapadwanj. The study therefore showed that bioenvironmental control strategy produced satisfactory results when compared to insecticidal spraying in terms of malaria control. The strategy therefore succeeded in maintaining transmission at low levels as envisaged, which was otherwise possible to a certain extent by spraying the residual insecticides. It should be mentioned that the spraying technique loses its effectiveness over a period of time due to insecticide resistance and social unacceptability, but the impact of the alternate strategy increases with the passage of time as more and more areas become free from mosquito production as a result of environmental modification.

Gujarat state had undergone serious drought conditions for several years until 1987, and there was population movement from drought affected areas to the Kheda district. Random checks of migrant populations showed 30-40 SPR, and

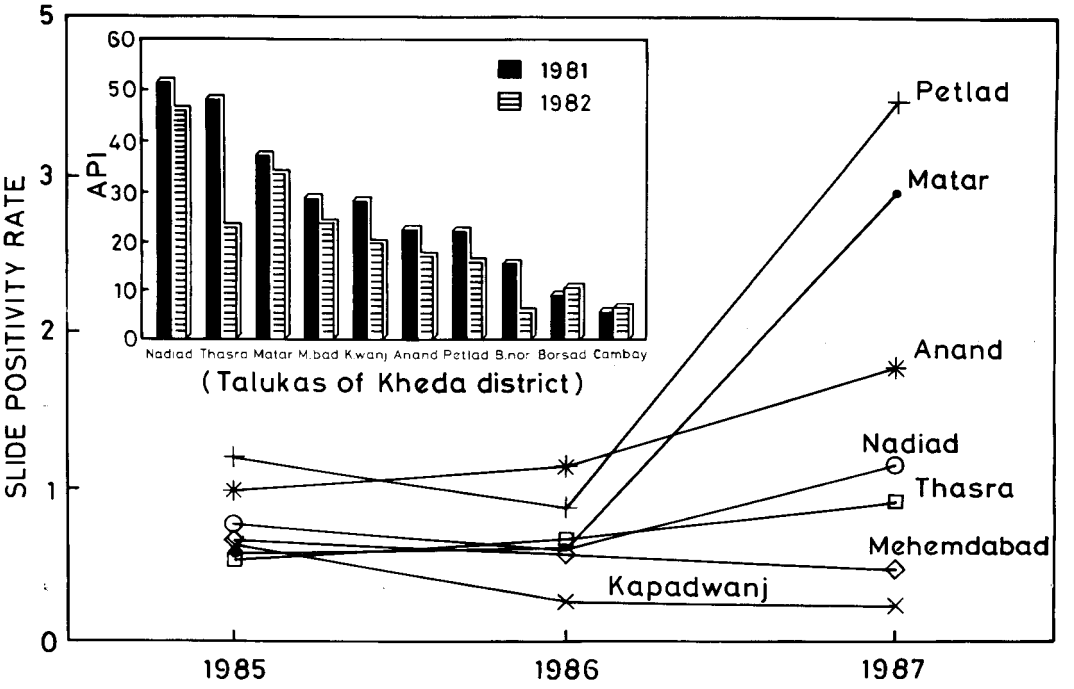

Fig. 5. Impact of intervention in Nadiad and neighboring talukas. In 1987 Kapadwanj taluka was also included in the experimental area. Malaria incidence was highest in Nadiad before the project was launched (see inset). Note that malaria was contained in Nadiad and Kapadwanj without insecticidal spraying.

Table 3. Actual cost of malaria control per million population in lakh rupees.

	Bioenvironmental*	DDT	HCH	Malathion
Pay and allowances	43.00	27.19	27.19	27.19
Capital (depreciation)	5.50	—	—	—
Antimalarials	1.20	1.20	1.20	1.20
Insecticides	—	34.00	37.00	199.00
Total	49.70	62.39	65.39	227.39

* Calculation based on 0.7 million population currently under protection.

60% of these were *P. falciparum* and 40% *P. vivax*. Although the migrant population was not included in Table 1, there is a strong possibility of enhanced indigenous transmission and that a large number of cases may have gone unrecorded. Another peculiar feature was a sudden spurt of *P. vivax* in the last quarter of 1987 when usually *P. falciparum* peaks. Reasons for this phenomenon are not very clear but may be the result of drought conditions or migration. The experiment is continuing to study the impact of alternate strategy during epidemic situations and dynamics of malaria transmission.

Costwise, a straight comparison of actual cost of malaria control by the two methods showed that per capita cost by the bioenvironmental strategy was lowest, as shown in Table 3 (Anonymous 1987). In addition, the bioenvironmental method has many collateral benefits which cannot be easily expressed in monetary terms. Because of the promising results of the Kheda experiment, the strategy was launched in phases at 9 other sites in the country in a mission mode under the science and technology project of the government of India. Each of these sites represents a different type of malaria problem. Results of the science and technology project will determine the future applicability of the bioenvironmental control of malaria in different malaria endemic zones of the country.

CONCLUSIONS

1. Bioenvironmental control of malaria so far has shown that the strategy is effective in the control of malaria in comparison to the spraying,

at least during the interepidemic period which may be an interval of 5 to 7 years or more.

2. The strategy has very high social acceptability and provides several collateral benefits to the society.

3. In comparison to residual spraying of insecticides, bioenvironmental strategy is the cheapest method of malaria control.

4. Malaria control should be primarily based on the bioenvironmental control strategy followed by a limited role for insecticides. Residual spraying should be applied to tackle epidemics or situations not amenable to control by the alternate strategy.

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