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Status of Insecticide Resistance of Malaria, Kala-azar and Japanese Encephalitis Vectors in Bangladesh, Bhutan, India and Nepal (BBIN)

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Foreword

In the South Asian region, vector-borne diseases such as malaria, kala-azar, Japanese encephalitis, filariasis, and dengue continue to be significant causes of morbidity, and in many instances mortality as well. Insecticides have played an important role in efforts at control of these vector-borne diseases. Among the neighboring countries—Bangladesh, Bhutan, India and Nepal (BBIN)—there has been a recent surge of interest in working together to curb the spread of resistance, both to the vector insecticides and to drugs that are used commonly in treatment of the diseases. The Environmental Health Project of USAID in Nepal has helped to create a network, BBIN, for establishing common approaches towards these diseases. It has initiated activities to share information on both insecticide resistance and malaria drug resistance through the development of inventories and status documents.

It is hoped that this document will serve a useful purpose not only in the BBIN countries, but also in the South Asian region in the overall planning of vector control through insecticide use and in considerations for the use of insecticide-treated mosquito nets. It is likely to be beneficial for assessing the choice of insecticides in light of the history of insecticide use in a particular geographical region, and the susceptibility level at the present time.

I am grateful to the Malaria Research Center (MRC) of India in making available Dr. P.K. Mittal, a highly experienced scientist in this field, to carry out a rapid review and compilation of the available information to produce this report.

The document will be made available to potential users through the Environmental Health Project (EHP) publication and the BBIN website, and by other means as they emerge.

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Abbreviations

BBIN	Bangladesh, Bhutan, India and Nepal
BHC	benzene hexachloride
Bti	*Bacillus thuringiensis*
DDT	dichloro-diphenyl-trichloroethane
DLD	dieldrin
EC	emulsifiable concentrate
EHP	Environmental Health Project
HCH	hexachlorocyclohexane
ICMR	Indian Center for Malaria Research
ICON	lambdacyhalothrin
IRS	indoor residual spraying
ITMN	insecticide treated mosquito nets
JE	Japanese encephalitis
KA	kala-azar
MPDCU	Malaria and Parasitic Disease Control Unit
MRC	Malaria Research Center
N.A	Not Available (in tables)
NAMP	National Anti Malaria Program India
NMEP	National Malaria Eradication Program
PHC	Primary Health Center
PKDL	post-KA dermal leishmaniasis
SEARO	Southeast Asia Regional Office of WHO
s.l.	sensu lato (=considered broadly)
USAID	United States Agency for International Development
WHO	World Health Organization
WDP	water dispersible powder
WP	wettable powder

About the Author

Dr. Pradeep Kumar Mittal has been a Senior Research Officer at the Malaria Research Center (ICMR), New Delhi, India, since 1981. Dr. Mittal's specializations in research are Entomology/Toxicology and Vector Control/Vector Resistance. During his time at the Center his work has mainly focused on vector biology and control, resistance to biocides, resistance to insecticides, and testing of new biocide formulations, insect growth regulators, and the use of plant products against mosquito vectors. Dr. Mittal has extensive publications to his credit. He holds a Ph.D. in zoology/toxicology and a M.Sc. degree in zoology (specializing in entomology), both from the University of Delhi.

Dr. Panduka M. Wijeyaratne is Resident Advisor to the HMG Ministry of Health/USAID Nepal Infectious Disease Program, where he directs a multifaceted program for the control and prevention of vector-borne diseases, particularly malaria, kala-azar, and Japanese encephalitis. Before joining the Environmental Health Project (EHP) in 1994, Dr. Wijeyaratne was Principal Program Officer (Health, Society, and Environment) with IDRC in Ottawa, Canada, for ten years. As Senior Tropical Disease Specialist in EHP/Washington, Dr. Wijeyaratne managed activities (focused on control of vector-borne diseases) in Zambia, Eritrea, Jordan, Nigeria, Malawi, Mozambique, and other countries. He has been a member of several advisory groups and technical steering committees for the World Health Organization and Rockefeller Foundation and the Canadian and Nigerian governments. Dr. Wijeyaratne has extensive experience with work in at least 35 countries including the United States, Canada, Sri Lanka, and Nigeria. His work also includes teaching, research and publications.

Ms. Sabeena Pandey is the Cross-border Activity Coordinator at EHP/USAID/Nepal Infectious Disease Program, where she has been working with Dr. Panduka Wijeyaratne in implementing Objective 5 related cross-border activities and the USAID/ANE/Bureau supported inter-country component activities. The principle activities included developing and maintaining a network of neighboring countries; Bangladesh, Bhutan, India and Nepal (BBIN), a BBIN website, malaria and Japanese encephalitis surveillance diagnosis and drug resistance common approaches and inventories on insecticide resistance and malaria drug resistance. Several inter-country conferences and workshops have been conducted in the implementation program that included numerous regional and international technical consultants as well as institutional networking. Ms. Pandey has a Master's Degree in Economics from University of Bombay, India, and has experience in developmental studies in and outside Nepal.

Executive Summary

Vector-borne diseases in the countries of the South Asian region are among the main causes of illness and death and have reemerged as the major public health problem. Bangladesh, Bhutan, India, and Nepal (BBIN) are endemic in malaria, kala-azar (KA), and Japanese encephalitis (JE). Transmitted through mosquito and sandfly vectors, these diseases have a high prevalence at border areas and are involved in cross-border transmission between these countries. There has been no official report of KA and JE in Bhutan, but it is considered to be at risk for their introduction.

The use of insecticides for vector control of these diseases will continue to play a major role in the programs of disease control. However, extensive and indiscriminate use of insecticides for the control of vector-borne diseases in the past has resulted in the development of resistance in vectors of malaria, KA and JE, and these diseases still continue to be a major public health problem in BBIN countries.

The type of insecticide and the application strategy differ from country to country and vector to vector, depending on susceptibility and resistance and on the behavior of the vector populations.

DDT is still being used in the control of malaria and KA in most parts of India, while its use in Nepal, Bangladesh, and Bhutan has been banned completely since 1990, 1994, and 1995 respectively. In Bangladesh however, some DDT is also being used against KA vectors, malathion is being used for indoor spraying against malaria vectors, and deltamethrin for the treatment of mosquito nets. In Bhutan, deltamethrin has been used for indoor spraying as well as for the impregnation of mosquito nets. In Nepal, malathion, pirimiphos-methyl, bendiocarb, and lambdacyhalothrin have been used for indoor spraying in selected areas. Recently deltamethrin has also been introduced.

Two major cross-border vectors of malaria in BBIN countries, namely *Anopheles minimus* and *An. dirus,* have been found to be fully susceptible to DDT and all other insecticides used to date in the control of malaria. These species have, however, developed behavioral resistance to DDT due to its tendency to repel vectors. After the introduction of synthetic pyrethroids, *An. minimus* has almost disappeared from Nepal.

Other vectors that have become resistant to certain insecticides from a cross-border point of view are *An. fluviatilis, An. annularis,* and *An. culicifacies s.l.* Two vectors of malaria in Nepal, *An. maculates* and *An. aconitus*, also have developed resistance to DDT.

In India among the Anopheles species, *An. culicifacies s.l.*, the major vector of malaria in most parts of the country, has developed widespread resistance to DDT, dieldrin/HCH, and also to malathion in several districts. Other vectors that are reported to be resistant to both DDT and dieldrin/HCH in India are *An. stephensi, An. annularis,* and *An. philppinensis.* In the delta region of Bangladesh the *An. sundaicus* malaria vector is fully susceptible to DDT but other malaria vectors such as *An. philppinensis*, *An. maculates,* and *An. aconitis* all have developed resistance to DDT. *An. aconitis,* additionally, has been reported to be resistant to dieldrin/HCH. Bhutan records *An. maculates* as resistant to DDT, but there is no record of its resistance to any other insecticides.

KA is transmitted by a sandfly vector, *Phlebotomus argentipes*. This species has been shown to be resistant to DDT in areas of KA transmission in Bihar. However, it is still susceptible to DDT in Bangladesh and West Bengal in India. Another species of sandfly *P. papatasi,* which is not a vector of KA but causes cutaneous leishmaniases, has been reported to be resistant to DDT and dieldrin in different areas. In Nepal, both *P. argentipes* and *P. papatasi* are reported as susceptible to malathion, bendiocarb, and synthetic pyrethroids.

Japanese encephalitis (JE) is transmitted by the *Culex vishnui* group of mosquitoes, namely *Cx. tritaeniorhynchus, Cx. vishnui*, *Cx. pseudovishnui,* and some other species such as *Cx. gelidus, Mansonia annulifera,* and *Ma. uniformis.* Most of these species have been reported to be resistant to DDT and dieldrin in most parts of India. *Cx. tritaeniorhynchus* and other JE vectors are susceptible to malathion in most of India, but in some areas resistance to malathion has also been reported. In Nepal, *Cx. tritaeniorhynchus* is susceptible to synthetic pyrethroids.

The inventory concludes that there is a lack of data pertaining to mechanisms of insecticide resistance in different vector species to address the problem of cross-resistance and multiple resistance to different insecticides. It reveals that there is a need for information exchange and networking between and among the different countries of the BBIN region on insecticide resistance data to tackle the resistance problem at the regional level and to establish research priorities in this area.

1. Introduction and Background

Vector-borne diseases are among the main causes of illness and death and constitute a major public health problem in the countries of the South Asian region. Bangladesh, Bhutan, India and Nepal (BBIN) are found to be endemic in malaria, kala-azar (KA) and Japanese encephalitis (JE). Transmitted through mosquito and sandfly vectors, these diseases have a high prevalence at border areas and are involved in cross-border transmission between these countries. Malaria, the most common of all these diseases, is transmitted through anopheline mosquito vectors. In all, there are twelve *Anopheles* species that spread malaria in these countries (Table 1). Of these, ten species are found in India. These include *Anopheles culicifacies*, *An. stephensi, An. fluviatilis, An. minimus, An. dirus,* and *An. sundaicus* as primary vectors and *An. annularis, An. philippinensis, An. jeyporiensis,* and *An. varuna* as secondary vectors. In addition to some of these species, *An. aconitus* has also been reported as a malaria vector from Bangladesh and *An. maculatus* from Bhutan and Nepal.

Besides malaria, certain states of India (Bihar and West Bengal) and bordering countries Nepal and Bangladesh are also highly endemic for KA (leishmaniasis), a disease transmitted through the sandfly vector *Phlebotomus argentipes* in these countries. In addition to malaria and KA, these countries are also prone to frequent epidemics of JE, an arboviral disease also transmitted through mosquito vectors of both Culex and Anopheles species (mainly the *Culex vishnui* group of mosquitoes). Though there has been no official report of KA and JE in Bhutan, the risk of these diseases does exist. Vectors for transmission have been identified in Bhutan, and these diseases are prevalent in bordering areas in neighboring countries.

The control of malaria and other vector-borne diseases in these countries is dependent mainly upon residual spraying of insecticides that interrupts their transmission. There are different categories of insecticides used for the control of vector-borne diseases. These include organochlorine (chlorinated hydrocarbon) insecticides such as DDT, hexachlorocyclohexane (HCH) benzene hexachloride (BHC), dieldrin, etc. Most of these insecticides have been banned because of their persistence in the environment and because the vectors have developed resistance to them. Though these insecticides have been banned completely in Bangladesh, Bhutan and Nepal, DDT is still being used in most parts of India against malaria and KA vectors.

The second category of insecticides used for the control of vector-borne diseases, the organophosphates, includes malathion, fenitrothion, fenthion, pirimiphos-methyl, and temephos chlorpyrifos. These insecticides do not persist in the environment but prolonged use of some of them has also resulted in the development of resistance in some vectors. Of these, malathion and pirimiphos-methyl have been used for indoor residual spraying (IRS), while fenthion and temephos have been used as larvicides. The third category of insecticide used in the control of vector-borne diseases is the carbamates, including propoxur and bendiocarb. Propoxur is used as a household insecticide and bendiocarb has been used for IRS. Both organophosphates and carbamates are biodegradable and do not persist or recycle in the environment and have a different mode of action than the organochlorine insecticides. Both categories of insecticides have been used to control vectors that are already resistant to DDT and other organochlorine insecticides. The fourth category of insecticides introduced for the control of vector-borne diseases is synthetic pyrethroids. These include deltamethrin, cyfluthrin, and lambdacyhalothrin. These have been used extensively in the past decade, particularly against vectors that have become resistant to other categories of insecticides and also those that rest outdoors in order to avoid contact with DDT-sprayed surfaces. Synthetic pyrethroids are fast-acting insecticides and produce a quick knockdown effect against vectors.

DDT, HCH (banned completely since 1997), and malathion have been used most extensively for indoor spraying against malaria and KA vectors in BBIN during the past four decades. However, due to their extensive use, varying degrees of resistance to them among disease vectors have been reported from different areas, and thus some other insecticides of the organophosphorus, carbamate, and synthetic pyrethroid group have also been used over the past decade to control resistant vector populations. The criteria for insecticide use vary from country to country, depending largely upon the susceptibility and resistance of the target vector populations to the insecticides.

Table 1. Malaria Vectors Prevalent in Bangladesh, Bhutan, India & Nepal (BBIN)

Anopheline species	**India (57)**	**Nepal (36)**	**Bhutan (8)**	**Bangladesh (31)**
An. Annularis	*	+	-	+
An. Culicifacies	+		-	
An. Dirus	+			+
An. Fluviatilis	+	+	+	
An. Jeyporiensis	*			
An. Maculates		+	+	
An. Minimus	+	+	+	+
An. Philippinensis	*			+
An. Stephensi	+			
An. Subpictus	?			
An. Sundaicus	+			*
An. Varuna	*			

Source: Subbarao 1998.
(Figures in parenthesis indicate the total number of anopheline species prevalent in the country).
+ Primary vectors
* Secondary vectors/local importance
? Suspected vectors
- Vectorial status not known

In Bangladesh, DDT spraying for malaria eradication was started in 1960, and spraying was continued throughout the country until 1971. After the independence of Bangladesh, only selective spraying of DDT was carried out in highly endemic areas. This was continued up to 1991. In 1991, DDT importation was banned, and only the remaining stock was used for the control of malaria and KA. Beginning in 1994, malathion and deltamethrin were used in small quantities for the control of malaria outbreaks and in epidemic-prone areas. Malathion is being used for selective residual spraying and deltamethrin is used for impregnation of mosquito nets. In 1999 and 2000, about 4,039 and 2,581 liters of malathion 57% emulsifiable concentrate (EC) formulation were used respectively for IRS. In addition, 3,000 liters of deltamethrin 2.5% EC has been used for the impregnation of mosquito nets. In addition, 45,338 kg and 39,990 kg of DDT 75% water dispersible powder (wdp) were used for KA control in the years 1999 and 2000. Besides these insecticides, which are being used as adulticides, the city corporations and municipalities are also using some organophosphorus insecticides as larvicides to reduce mosquito nuisance and malaria transmission in these areas.

In Bhutan, the malaria eradication program began in 1962 with the introduction of DDT in the form of IRS. In 1992, the emphasis was changed from malaria eradication to malaria control, and in 1995 the use of DDT in malaria was stopped. DDT was replaced by an insecticide of the synthetic pyrethroid group. Deltamethrin was introduced for indoor spraying and also for impregnation of mosquito nets. In 1997, about 8,900 kg of deltamethrin (2.5% wdp) was used for IRS, and in 1999, approximately 3,161 liters of deltamethrin 2.5% flow was used for the impregnation of mosquito nets (Annex 1). In addition to deltamethrin, which was used as an adulticide, 267 liters temephos (50% EC), an organophosphorus insecticide, and 300 liters of *Bacillus thuringiensis* (Bti) were also used as larvicides in 1998.

In India, DDT has been in use for malaria control operations since 1946. The introduction of DDT in public health, first as a larvicide and later as an adulticide through IRS, brought about a revolution, and malaria eradication was thought to be an achievable task. Spraying of DDT, particularly as IRS, almost eradicated malaria in areas that were otherwise very difficult to tackle. However, continued and extensive use of DDT lead to the development of physiological resistance in certain vectors while a behavioral change to avoid contact with insecticide was noticed among other vectors. In spite of this, DDT is still being used in a large number of districts in India against malaria and KA vectors (Annex 2).

In addition to DDT spraying, other organochlorine insecticides such as dieldrin and BHC were also introduced simultaneously for indoor spraying against malaria vectors, but dieldrin was soon withdrawn, while BHC continued to be sprayed in some areas with DDT resistant vector populations until 1977. However, after 1997 the use of BHC in public health was banned completely. In areas where vectors have developed double resistance to DDT and HCH, malathion has been used for indoor spraying, but resistance against malathion has also been reported in malaria vectors in some areas. In addition to these insecticides some other insecticide formulations of organophosphorus compounds, carbamates, and synthetic pyrethroids have also been used during the past decade. Among the synthetic pyrethroids, deltamethrin (2.5% wettable powder, or wp), cyfluthrin (10% wp), and lambdacyhalothrin (10% wp) have been used for indoor spraying in some high-risk areas and areas with triple resistant (DDT, HCH and malathion) vectors and also in some areas to tackle malaria outbreaks and epidemic situations. Besides indoor spraying, synthetic pyrethroids have also been evaluated in the form of insecticide treated mosquito nets (ITMN) in different trials against malaria vectors, and now ITMNs are being used under a pilot project in the northeastern states of India. In urban areas, fenthion and temephos, two organophosphorus insecticides, are being used as larvicides under the urban malaria scheme. Bti, a bacterial insecticide has also been used as a larvicide during the past decade to control malaria and the mosquito nuisance in some towns.

In Nepal, the use of DDT in malaria control was discontinued from 1990 onwards, but malathion was used for indoor spraying until 1997. In addition to DDT and malathion, pirimiphos-methyl (another organophosphate), bendiocarb (a carbamate insecticide), and lambdacyhalothrin (ICON, a synthetic pyrethroid) have also been used for indoor spraying in selected areas. Though the use of pirimiphos-methyl and bendiocarb was discontinued after 1990 and 1993 respectively, ICON is still being used for indoor spraying in selected areas. During the year 2000, 20 MT of another synthetic pyrethroid, K-Othrine (deltamethrin 2.5% wp) was used for indoor spraying in addition to 253 kg of ICON (10% wp).

Synthetic pyrethroids are now getting priority use, particularly for impregnation of mosquito nets. The use of ITMNs is now being accepted as a viable strategy to control malaria transmitted by mosquito vectors that are exophilic (tending to rest outdoors) and anthropophagic (feeding on humans).

Purpose of Inventory

Extensive and indiscriminate use of insecticides for the control of vector-borne diseases in the past has resulted in the development of resistance in vectors of malaria, KA, and JE, and these diseases still continue to be a major public health problem in BBIN countries. To assess the magnitude of the problem of insecticide resistance in vectors of malaria, KA, and JE and to systematize the information on insecticide resistance, there is a need for a database on insecticide use and resistance in vector populations. In view of this, a status on insecticide resistance in BBIN has been prepared with the objectives listed below.

1) To compile and systematize information on insecticides used in Bangladesh, Bhutan, India and Nepal for the control of malaria, KA, and JE through review of documented reports (1990 onwards)

2) To collect and compile documents on insecticide resistance status of malaria, KA, and JE vectors in the BBIN countries through literature and document searches and personal contacts (1990 onwards)

3) To make a catalog of institutions and individuals involved in cross-border insecticide resistance issues

4) To prepare a report of cross-border insecticide resistance based on information and publications from Bangladesh, Bhutan, India, and Nepal.

2. Status of Insecticide Resistance in Vectors of Malaria, KA and JE

2.1. Bangladesh

Six species of *Anopheles* have been reported as malaria vectors in Bangladesh. Of these, five are primary vectors (Subbarao 1998). These are *An. aconitus, An. annularis, An. dirus, An. minimus* and *An. philippinensis.* Besides these *An. sundaicus* has been reported as a secondary vector of local importance. Recent reports however do not show the presence of *An. minimus* and *An. sundaicus.* Instead, *An. vagus* has been reported as a malaria vector and *An. maculatus* as a suspected vector of malaria in Bangladesh (Bangali 2000). There are only a few reports of insecticide resistance in malaria vectors from Bangladesh. Susceptibility tests carried out using WHO discriminating doses have revealed resistance to DDT in *An. aconitus* (WHO 1992, 1998), *An. annularis* (WHO 1992, Kondrashin 1992, WHO 1998), and *An. philippinensis* (MPDCU 1996) while *An. dirus* remains fully susceptible to DDT. However, *An. vagus*, another malaria vector reported in Bangladesh, has also shown resistance to DDT. Though *An. dirus* is fully susceptible to DDT, it does not come in contact with DDT due to its excito-repellency, that is, its tendency to avoid surfaces sprayed with DDT. It prefers to rest outdoors. There is, however, no other confirmed report of resistance to any other insecticide in any of the vector species reported from Bangladesh.

2.1.1. Anopheles aconitus

An. aconitus, a primary vector of malaria in Bangladesh, has been reported to be resistant to DDT (WHO 1992), but there is no record of its resistance to any other insecticide used in malaria control. Subsequent reports have shown only low levels of resistance (78–87% mortality to DDT 4%) in Mymensingh district (MPDCU 1999). No information is available on its susceptibility status to other insecticides and also against DDT from other areas of Bangladesh.

2.1.2. An. annularis

An. Annularis, another malaria vector in Bangladesh, is more widely distributed than *An. aconitus.* This species has also been reported as resistant to DDT since the 1980s (WHO 1992). Recent reports have shown its resistance to DDT from Sylhet district (75%

mortality), Narayanganj district (62–70% mortality), and Sunamganj district (80–90% mortality), but it is still fully susceptible to malathion and fenitrothion (MPDCU 1995, 1997, 2001). There is, however, no report of its susceptibility status to pyrethroids.

2.1.3. An. dirus

An. dirus, an important vector of malaria in Bangladesh because of its high anthropophagic nature, has so far remained fully susceptible to DDT and all other insecticides used for malaria control. There is no record of any degree of resistance to any insecticide in *An. dirus.* Recent reports from Hobiganj district, where it is found in high densities, have shown 100% susceptibility to DDT 4%, malathion 5%, deltamethrin 0.025%, dermethrin 0.25%, and lambdacyhalothrin 0.05%. Even though *An. dirus* is 100% susceptible to all the insecticides, it is prevalent in some areas because it rests only outdoors and thus avoids direct contact with insecticide-sprayed surfaces.

2.1.4. An. maculatus

An. maculatus, a vector of malaria in Nepal and Bhutan, has not been shown to be a malaria parasite in Bangladesh. This species is prevalent in Bandarban district in Bangladesh and has been found to be resistant to DDT but fully susceptible to malathion and synthetic pyrethroids (MPDCU 2000). Subsequent reports have confirmed these results. Some tolerance to fenitrothion was noticed, but this information needs further confirmation (MPDCU 2001)

2.1.5. An. minimus

An. minimus has also been reported as a primary vector of malaria in Bangladesh, but recent reports do not show its prevalence there. There are some reports of disappearance of *An. minimus* as a result of DDT spraying in neighboring areas in India. It is possible that this species might have also disappeared from Bangladesh because of spraying of DDT. Recent reports from India show the reappearance of *An. minimus* from some unsprayed areas. Even though it is fully susceptible to DDT, it avoids contact with DDT because of its high excito-repellency.

2.1.6. An. philippinensis

An. philippinensis was not reported to be resistant to DDT until the 1990s. However, subsequent reports on susceptibility status of *An. philippinensis* from Sylhet district in Bangladesh have shown its resistance to DDT (67–75% mortality) and some tolerance to malathion (94.6–100% mortality). It is 100% susceptible to synthetic pyrethroid (MPDCU 1996, 1997). Susceptibility of *An. philippinensis* to malathion in Bandarban district was also 100%. (MPDCU 2000, 2001).

2.1.7. An. sundaicus

An. sundaicus has been reported as a malaria vector of secondary importance in Bangladesh. Recent reports do not show the prevalence of *An. sundaicus* in Bangladesh, and thus, no information of its resistance status to insecticides is available.

2.1.8. An. vagus

An. vagus, a widely distributed non-vector species in India and Nepal has, however, been reported as a malaria vector in Bangladesh (Bangali 2000). In Bangladesh, the species is also almost widely distributed throughout the country and has been reported to be resistant to DDT since the 1980s (WHO 1992). Subsequent reports have confirmed high resistance to DDT from various districts including Sunamganj and Bandarban (MPDCU 2001), as well as Mymensingh, Netrokona (1995), and Naryanganj and Kishoreganj (MPDCU 1997), but this species is still 100% susceptible to fenitrothion and synthetic pyrethroids (MPDCU 1997, 2001).

2.2. Bhutan

Three Anopheline species have been reported as malaria vectors in Bhutan. These are *An. fluviatilis*, *An. maculatus* and *An. minimus*. In addition to these, *An. dirus* has also been listed as a malaria vector in Bhutan (Kalra & Prakash 1994). There is no report of insecticide resistance in any of these malaria vectors except in *An. maculates* (WHO 1992). *An. minimus*, formerly a major vector of malaria, was reported to have disappeared after DDT indoor spraying and *An. maculatus* was considered to have taken over the role of the primary vector. *An. maculatus* from Bhutan and in neighboring areas in India has been reported to have developed resistance to DDT. However, *An. maculatus* is not a vector of malaria in India. Recent observations have shown the presence of *An. minimus* in outdoor collections in Bhutan and thus DDT, which has a strong excito-repellant action against *An. minimus*, has no role in malaria control in Bhutan. It has been replaced by deltamethrin for indoor spraying and also to prepare ITMNs.

2.3. India

There are six primary vectors of malaria in India. These are *An. culicifacies*, *An. stephensi*, *An. fluviatilis*, *An. minimus*, *An. dirus* and *An. sundaicus*. In addition to these, An. annularis, An. philippinensis, An. varuna and An. jeyporiensis have also been reported as malaria vectors of secondary importance. *An. aconitus* and *An. Maculates*—the two malaria vectors reported from Bangladesh, Bhutan, and Nepal—are also found in bordering areas of India, but there is no report of their vectorial status in India. Sporozoite positive specimens of *An. subpictus*, which is a vector of malaria in Indonesia and Sri Lanka, has also been reported from India (Paniker et. al. 1981, Kulkarni 1983). Of the six primary vectors, *An. culicifacies* is most widely distributed throughout the rural plain areas in India and has been reported to be resistant to most of the insecticides that have been used for malaria control in India. *An. culicifacies* is a complex of five sibling species in India but for insecticide resistance most of the reports are for the broad populations. An. stephensi, another prominent vector in urban areas, has also been reported to be resistant to different groups of insecticides even though these insecticides are not used for indoor spraying against An. stephensi because in urban areas the emphasis is given on antilarval methods.

Among other primary vectors, only *An. fluviatilis* has been reported to be resistant to DDT and HCH/dieldrin in certain parts of the country while remaining fully susceptible in other areas. The other three primary vectors, *An. minimus*, *An. dirus*, and *An. sundaicus* have not been reported to be resistant to any of the insecticides used against them. In spite of their susceptibility to insecticides, these species have been reported to transmit malaria in certain parts of the country, particularly in the northeastern states. *An. minimus* and *An. dirus* prefer to rest outdoors in DDT sprayed areas because of the excito-repellency effect of DDT. Among the secondary vectors, *An. annularis*, *An. philippinensis*, and *An. varuna* are reported to be resistant to DDT and BHC/dieldrin in certain areas but there is no report of insecticide resistance in *An. jeyporiensis*. The insecticide resistance status of each vector species found in India with particular emphasis on *An. culicifacies* and *An. stephensi* is described below.

2.3.1. Anopheles culicifacies

An. culicifacies (Krishnamurthy and Singh 1962) is the most prominent of the primary malaria vectors in India, being responsible for about 60–70% of malaria cases reported from the country. It is most widely distributed throughout the rural plain areas of the country. *Anopheles culicifacies s.l.* has been reported to differ in terms of bionomics in different regions in the country (Rao 1984). Later it was recognized as a complex of four sibling species, namely spp. A, B, C & D (Subbarao et. al. 1988, Subbarao 1998, Kar et. al. 1997). One more sibling species of *An. culicifacies,* sp. E, has been reported from the Rameshwaram Islands in southern India. For insecticide resistance in *An. culicifacies* most of the reports are based on *An. culicifacies s. l.* There are, however, some reports (Ragavendra et al. 1991, 1992, Subbarao and Sharma, 1997, Subbarao et al. 1988 and Singh et al. 2002) that give information on insecticide resistance in different sibling species of *An. culicifacies. An. culicifacies s.l.* remained highly susceptible to DDT during the first ten years of its use in malaria control in India. However, reports of reduced susceptibility to DDT based on the median lethal concentrations started appearing in 1956 (Bhatia et. al. 1958, Rao & Bhatia 1957, Pal 1958).

The first confirmed report of DDT resistance in *An. culicifacies* was from Panch Mahal district in Gujarat (Rahman 1959). Subsequently reports of resistance to DDT in *An. culicifacies* were published from various states including Maharashtra, Karnataka, Tamil Nadu, Uttar Pradesh, Rajasthan, and Madhya Pradesh (Luen and Shalby 1962, Krishnamurthy and Singh 1962, Bhombore 1963, Das 1966, Raghavan 1967). Simultaneously, resistance to dieldrin/HCH was also reported from Gujarat, Maharashtra, Uttar Pradesh, and some other states in India (Pal 1958, Patel et. al.1958, Sharma & Samnotra 1962, Bhatia & Deobhankar 1963). The first report of resistance to malathion, the third insecticide used for indoor spraying in India, also came from western India in 1977 (Rajagopal 1977). Until 1990, varying degrees of resistance to DDT and dieldrin/HCH in *An. culicifacies* was reported from all over the country (Brown and Pal

1971, Ansari et al. 1986, 1988, NMEP 1990, Sharma et al. 1982, 1986, Singh and Sharma 1989, Singh et al. 1989). Triple resistance to DDT, dieldrin/HCH, and malathion was also reported from Gujarat, Haryana and Maharashtra (NMEP 1991, Vittal and Bhote 1983, Vittal and Deshpandae 1983, Vittal 1983, Subbarao 1979, 1984).

Varying degrees of resistance to insecticides in *An. culicifacies* in different areas in India was explained after it was revealed that *An. culicifacies* comprises four sibling species that differ in their susceptibility to insecticides (Subbarao et al. 1988, 1998, Raghavendra 1991, 1992). Resistance to DDT in species B, which is a non-vector, builds up faster than the sympatric population of sibling sp. A (which is a vector). Similar observation with malathion resistance in species A, which takes a long time to precipitate resistance, and in species B and C, which develop resistance very quickly, has been reported (Raghavendra 1991, 1992). Based on the differential susceptibility and rate of development of resistance in different sibling species of *An. culicifacies,* a modified spraying strategy for the insecticide has been recommended (Subbarao and Sharma 1997). It was also noticed that *An. culicifacies sp. C* had developed resistance to malathion in areas that were not sprayed for malaria control, but due to the agricultural use of organophosphorus insecticides the vector has developed resistance (Sharma 1996). Earlier, Wattal et al. (1981) also suggested the role of agricultural insecticides in precipitating resistance among vectors.

The differential distribution and composition of different sibling species of *An. culicifacies* in different areas could probably explain the rapid development of triple resistance to DDT, HCH and malathion in Gujarat, Maharashtra and other parts of India, where sp. B and sp. C are the predominant sibling species. In areas with triple resistance to DDT, HCH and malathion that are under high risk of malaria transmission, synthetic pyrethroids are being used. Though the *An. culicifacies* population from different areas both sprayed and unsprayed with pyrethroids have remained susceptible to synthetic pyrethroids (Das et al. 1986, Ansari et al. 1990, Bansal & Singh 1996, Yadav et al. 1996, Gill et al. 1997, Kumari et al. 1998), recent reports on reduced susceptibility to deltamethrin in *An. culicifacies* from Rameshwaram Islands (Mittal et al. 2002) and the development of resistance from Surat (Singh et al. 2002), suggest the need for an alternative strategy and management of the problem of insecticide resistance in *An. culicifacies*. Use of a bioenvironmental vector control method and rotation of insecticides have been suggested as the possible methods for delaying the development and management of insecticide resistance (Sharma 1996, Pillai 1996).

2.3.2. Anopheles stephensi

Anopheles stephensi is another major vector of malaria prevalent in urban areas in India. It has also been reported to be resistant to DDT, HCH/dieldrin, and malathion in different areas. Even though DDT and HCH are not directly used against this vector in urban areas, their use in periurban and rural areas has induced resistance in this species. However in rural areas, *An. stephensi* is not a serious vector and therefore its resistance to residual insecticides is not a problem for malaria control. In urban areas, control of *An. stephensi*-induced malaria is primarily dependent on antilarval methods and space spraying of insecticides.

There are, however, some technical problems in the use of larvicides against *An. stephensi* in potable waters. Resistance to temephos, an organophosphorus larvicide of choice, has also been reported in some cities. Initially DDT was also used as larvicide and therefore resistance to DDT in *An. stephensi* was first reported in larvae in 1955 in Erode Town of Tamil Nadu (Rajagopalan et. al. 1955). Subsequently, DDT resistance was also detected in adult mosquitoes in different areas. Resistance to DDT and dieldrin/HCH is now widespread throughout the country (Kumari et. al. 1998).

Resistance to malathion has been reported from Tamil Nadu, Karnataka, Gujarat, Haryana, and other areas. In Rajasthan however, this species is still susceptible to malathion. *An. stephensi* has also shown a tendency to develop resistance against various insecticides under laboratory selection (Chitra and Pillai 1984, Verma and Rahman 1986, Chakravorty and Kalyansundram 1986). Development of resistance to microbial toxins of *Bacillus sphaericus* has also been reported recently in *An. stephensi* (Mittal et al. 1998). These studies indicate the possibility of development of resistance in *An. stephensi* to all categories of insecticides that could be used for the control of *An. stephensi*.

2.3.3. Anopheles fluviatilis

Anopheles fluviatilis is another significant malaria vector found in the foothills of Uttar Pradesh, and in the states of Orissa, Madhya Pradesh, Gujarat, Maharashtra, Rajasthan, Himachal Pradesh, Andhra Pradesh, Karnataka, Tamil Nadu, and some other areas. Three sibling species, S T and U, have been identified recently in the *An. fluviatilis* complex (Subbarao 1998). Of these, species S is an efficient vector, while species T is a poor vector (Nanda et. al. 2000). However, the reports of insecticide resistance status of *An. fluviatilis* are based on the broad population. *Anopheles fluviatilis* is still susceptible to DDT in Orissa where it is an efficient and a primary vector of malaria.

Resistance to DDT has been reported recently from Puri and Balasore districts in Orissa (NAMP unpublished). In the states of Gujarat, Maharashtra, Himachal Pradesh, Madhya Pradesh and Uttar Pradesh, it has been reported to be resistant to DDT (Sharma et al. 1999, Kumari 1998). Double resistance to DDT and dieldrin/HCH has been reported from eight districts: five in Karnataka and one each in Himachal Pradesh (Una), Tamil Nadu (Coimbatore), and Bihar (Dhanbad). Resistance to dieldrin alone has been found in two districts: Shimoga in Karnataka and Nilgiri in Tamil Nadu (Kumari et al. 1998). There is, however, no report of resistance to malathion in *An. fluviatilis*.

It has also been reported as 100% susceptible to fenitrothion in Gujarat, Maharashtra, and Andhra Pardesh (Kumari et al. 1998) and to deltamethrin and lambdacyhalothrin in Uttar Pradesh (Sharma et. al. 1999). In Karnataka (formerly Mysore state), *An. fluviatilis* was the predominant vector responsible for maintaining holoendemic malaria. The species used to breed in slow moving streams. After the introduction of DDT spraying and changes in the forest ecology, *An. fluviatilis* not only disappeared from Karnataka but that state became free of malaria also (Sharma 1996). However, malaria transmission due to *An. culicifacies* has now been reported from these areas. Even though *An. fluviatilis* is still susceptible to DDT in Orissa, (Sahu 1990, Sahu and Patra 1995), where it is a major vector, malaria transmission continues to persist.

In Orissa, *An. fluviatilis* has reportedly become exophilic. Another important reason for continuous malaria transmission in this area is poor coverage of DDT spraying and high anthropophagy in *An. fluviatilis* in forest areas.

2.3.4. Anopheles minimus

An. minimus, prevalent in northeastern states, is a primary malaria vector in this region (Bhatnagar et al. 1982). This species was also important as the malaria vector in the Nainital and Terai districts of Uttar Pradesh in the pre-DDT years. However, after the introduction of DDT in malaria control and changes in the ecosystem, *An. minimus* was reported to have disappeared from Terai in Uttar Pradesh (Chakravorti and Singh 1957).

Later studies carried out in northeastern states also indicated the disappearance of *An. minimus* after DDT spraying (Rajagopal 1976). However, further studies not only confirmed the presence of *An. minimus* but designated it as a malaria vector in different areas (Bhatnagar et al. 1982, Das et al. 1985, 1990). There are very few reports on the resistance status of *An. minimus* to insecticides because of its limited habitat. All these reports show its complete susceptibility to DDT and other insecticides against which this species has been tested (Das et al. 1990, 1987, 2000, Prakash et al. 1996). Even though *An. minimus* is fully susceptible to DDT, it remains a major malaria vector in this region. This species has developed excito-repellency and does not come in contact with the insecticide for the duration that is required to kill it. *An. minimus* prefers to rest outdoors, though indoor collections have also been reported from unsprayed structures. In order to counter the vector’s exophilic behavior and its high anthropophagic nature, ITMNs treated with synthetic pyrethroids have now been introduced in the northeastern states to control *An. minimus*-induced malaria in these areas.

2.3.5. Anopheles dirus

An. dirus (balabacensis balabacensis) is the primary vector of malaria in northeastern states of India. There are very few reports on the insecticide resistance status of this species, but all of these show complete susceptibility of *An. dirus* to DDT, dieldrin/HCH, and malathion. However, this species is predominantly exophilic and anthropophagic, factors that have made the species thrive as a resilient vector.

2.3.6. Anopheles sundaicus

An. sundaicus is a primary vector of malaria in the Andaman and Nicobar Islands, though there are reports of its existence in the coastal areas of Orissa and Andhra Pradesh on the mainland (Rao 1984). This species has now disappeared from the mainland with a small focus in the Kutch area of Gujarat (Singh et al. 1985). *An. sundaicus* has so far remained fully susceptible to DDT, dieldrin/HCH, malathion, and deltamethrin, which have been used for indoor spraying for malaria control in India (Kalra 1981, Kumari and Sharma 1994, Das 2001).

In addition to the Andaman and Nicobar Islands of India, these species also exist in the delta region of Bangladesh. Though *An. sundaicus* is fully susceptible to DDT and other insecticides in the mentioned islands, it has adapted to outdoor resting habitats (Kumari and Sharma 1994). This species in the Nicobar islands is predominantly zoophagic. Such conditions have increased its survival rates despite high susceptibility to DDT and other insecticides.

2.3.7. Anopheles annularis

An. annularis is widely distributed in India, Nepal and Bangladesh (Krishnamurthy and Singh 1962). Though it is a prominent vector in Nepal and Bangladesh, it has been recognized as a malaria vector of only secondary importance in India (Dash et al. 1982, Rao 1984, Gunasekaran et al. 1989). Resistance to DDT in *An. annularis* was first reported from Meerut district in Uttar Pradesh in 1962 (Krishnamurthy and Singh 1962). Ever since, this species has become resistant to DDT in different parts of the country (Azeez 1964, Brown and Pal 1971, NMEP 1991). Double resistance to DDT and dieldrin/HCH has also been reported from Orissa (Chand and Yadav 1991, Sahu et al. 1990), Rajasthan (Bansal and Singh 1996), Assam (Das et al. 1997), and other parts of the country (Pillai 1996). The species is however susceptible to malathion, fenitrothion, and deltamethrin in areas where it has been tested against these insecticides (Chand and Yadav 1991, Bansal and Singh 1996, Kumari et al. 1998, Das et al. 2000, Sharma 1993).

2.3.8. Anopheles philippinensis

An. philippinensis (An. nivipus) in India is a predominant species appearing in the states of Assam, Arunachal Pradesh, and Meghalaya. It is also possible that both species of this complex might occur in the same area, but lately it has been established that *An. nivipus,* is now a predominant vector in these states (Subbarao 1998). *An. philippinensis,* once a dominant vector in the delta region of West Bengal, is now almost absent (Rao 1984). Though appearance of *An. philippinensis* was indicated in Burnihat, Meghalaya (Rajagopal 1976), present studies have shown the existence of only *An. nivipus.* In recent years, insecticide susceptibility studies on members of *An. nivipus (An. philippinensis)* have shown the development of resistance to DDT in some areas of Assam and Arunachal Pradesh (Das et al. 1997, Kumari et al. 1998). However, in Bihar and Bengal this species is still susceptible to DDT (Kumari et al. 1998, Das et al. 2000). There is, however, no report of resistance in *An. philippinensis* (*An. nivipus)* to dieldrin and malathion.

2.3.9. Anopheles varuna and Anopheles Jeyporiensis

An.varuna and *An. jeyporiensis,* though reported as secondary vectors of malaria in India (Rao 1984, Subbarao 1998), are now seemingly nonexistent. There is almost complete absence of reports on the vectorial potential and also insecticide resistance status of *An. jeyporiensis.* However, resistance to DDT in *An. varuna* in India has been reported (WHO 1992, Pillai 1996).

In addition, to the six primary and four secondary malaria vectors reported from India (Subbarao 1998), *An. subpictus* has also been indicated in some coastal villages of southern India (Panikar et al. 1981) and Baster district (Kulkarni 1983). *An. subpictus*, a prolific breeder in most parts of the country during the rainy season, could play a disastrous role in malaria transmission if it becomes a vector in these areas. This species has been reported to be resistance to DDT and dieldrin/HCH in Gujarat (NAMP 1991), Rajasthan (Bansal and Singh 1996), and other areas, but remains susceptible to malathion in these areas.

2.4. Nepal

An. annularis, An. fluviatilis, An. maculatus, and *An. minimus* are the four anopheline species that have been reported as malaria vectors in Nepal. However, Kondrashin (1992) has included *An. aconitus* and *An. culicifacies* also in the list. Of these, *An. maculatus, An. aconitus, An. annularis, An. fluviatilis* and *An. culicifacies* have been reported to be resistant to DDT and HCH/dieldrin (WHO 1992, Kondrashin 1992), while there is no report of insecticide resistance in *An. Minimus* in Nepal. Recent studies have shown susceptibility of *An. annularis* to malathion, bendiocarb, and deltamethrin, but confirmation is required against lambdacyhalothrin. *An. fluviatilis* has been reported to be 100% susceptible to both deltamethrin and lambdacyhalothrin (EHP 2000).

2.4.1. Anopheles aconitus

Anopheles aconitus is not included as a malaria vector in Nepal, but has been reported as a malaria vector by Kondrashin in 1992 in neighboring Bangladesh. This species has been reported as resistant to DDT since the past decade (WHO 1992), but no information is available on its present status of resistance to DDT and other insecticides.

2.4.2. Anopheles annularis

An. annularis, a primary vector of malaria and one of the predominant anopheline species in Nepal, has shown a high degree of resistance to DDT (WHO 1992, Kondrashin 1992, Anon. 2000), but it is still susceptible to organophosphate and carbamate pesticides (EHP 2000, Anon. 2000). Recent reports have shown the development of resistance in *An. annularis* to synthetic pyrethroids in some areas. In Harpur, Nawalparasi district, *An. bannularis* showed only 80% mortality against lambdacyhalothrin 0.1% (Anonymous 1997) whereas in Pipara, Mahottari, district it showed 95–96% mortality against deltamethrin and lambdacyhalothrin and only 58% mortality against permethrin.

2.4.3. Anopheles culicifacies

An. culicifacies, a major vector of malaria in rural plain areas in India, is a non-vector species in Nepal. This species has been reported to be resistant to DDT (WHO 1992, Kondrashin 1992) in Nepal also, but recent studies on susceptibility tests carried out against a synthetic pyrethroid, lambdacyhalothrin (0.1%) from T. Ranibus in Sindhuli district have shown its complete susceptibility to this insecticide.

2.4.4. Anopheles fluviatilis

An. fluviatilis, a major vector of malaria in Nepal, has been reported as resistant to DDT/ HCH since the past decade (WHO 1992, Kondrashin 1992). Recent reports have shown only a low degree (80–85% mortality) of resistance to DDT in *An. fluviatilis* and have also given some indications about precipitation of resistance to synthetic pyrethroids in different areas (Anon. 2000, 2001). However this species has shown complete susceptibility to an organophosphate (malathion) and a carbamate (bendiocarb).

2.4.5. Anopheles maculatus

An. maculatus, also a primary vector of malaria in Nepal, has already been reported as resistant to DDT over the last decade (WHO 1992). Its status with regard to DDT in recent years is not known because DDT is not used at present in Nepal. However, this species has shown some indication for the development of resistance to synthetic pyrethroids, particularly lambdacyhalothrin in Surana, Jhapa, district, where this insecticide has been used in malaria control during the last few years. In some areas however, *An. maculatus* is still fully susceptible to synthetic pyrethroids.

2.4.6. Anopheles minimus

An. minimus, reported as a vector of malaria in Nepal, has shown susceptibility to DDT and other insecticides (Kondrashin 1992). In recent years, however, there is no report of its prevalence and susceptibility status to insecticides in Nepal. *An. minimus,* also a vector in the northeastern region in India, was reported to have disappeared after the introduction of DDT in the malaria control program, but this species is now commonly found in Assam, particularly in areas where there is no indoor spraying.

2.5. Present status of insecticide resistance in the Kala-azar vector Phlebotomus Argentipes in BBIN

2.5.1. Bangladesh

KA was one of the major public health problems in Bangladesh and the adjoining Indian areas of West Bengal, Bihar, and the Brahmaputra River Valley during the pre-DDT years. The Malaria Eradication Program involving widespread use of DDT residual spraying continued until 1971. This brought down the incidence of KA, in addition to the high susceptibility of KA vector to DDT. Except for a few cases of post KA dermal leishmaniasis (PKDL), KA almost disappeared from Bangladesh.

However, a resurgence of KA including PKDL was reported in the late seventies, after mass-scale spraying of DDT was discontinued. During the last few years, the KA situation has assumed epidemic proportions with the number of reported cases increasing from a total of 2,397 in 1993 to 7,032 in 1998 (Bangali 2000). Residual spraying of DDT is very effective in controlling sandfly vectors in Bangladesh (WHO 1990). However, spraying should be preceded and followed by an assessment of susceptibility status of *P. argentipes* to DDT and other insecticides.

2.5.2. Bhutan

There is no official report of KA in Bhutan, and thus, there is no report about insecticide resistance in the KA vector from Bhutan.

2.5.3. India

Though *Phlebotomus argentipes,* the vector of KA, is found in different states in India, KA is endemic in Bihar and West Bengal and in few districts in eastern Uttar Pradesh in India. Other areas are completely free from this disease. Although earlier there was no separate control program for KA, spraying of DDT for malaria control resulted in the collateral control of KA in Bihar and West Bengal, as the vector was highly susceptible to indoor spraying of DDT. However, continued spraying of DDT has resulted in the precipitation of DDT resistance in *P. argentipes* in various districts of KA endemic areas in Bihar (Mukhopadhyay et al. 1990, NMEP 1991, WHO 1992, Kaul 1993).

Though the vector's resistance to DDT in certain districts of Bihar has been reported, it is still susceptible to DDT in West Bengal and some of the districts of Bihar (Chandra et al. 1995, Basak and Tandon 1995, Mukhopadhyay et al. 1996). *P. argentipes* is fully susceptible to malathion, deltamethrin, and other insecticides that can be used for indoor spraying. *P. papatasi,* another sandfly found along with *P. argentipes,* has been reported to be resistant to dieldrin and propoxur.

2.5.4. Nepal

There is no information about resistance to DDT in *P. argentipes* in Nepal, though resistance to DDT has been reported in the Indian territory. Since DDT in not used anymore in Nepal, there is no information on susceptibility and resistance. *P. argentipes* has been found to be susceptible to all other insecticides such as malathion, bendiocarb, deltamethrin, and lambdacyhalothrin, which have been used for indoor spraying in Nepal (EHP 2001) *P. papatasi,* found along with *P. argeptipes,* has not shown 100% susceptibility to deltamethrin. The present information is not sufficient to conclude the resistance status of *P. argentipes* and *P. papatasi* in Nepal.

2.6. Present status of insecticide resistance in Japanese encephalitis vectors in BBIN

2.6.1. Bangladesh

JE is not a major public health problem in Bangladesh, though sporadic cases of JE are reported by clinicians. This is because there is no definite control program to identify the magnitude of the problem, and thus, precise information is not yet available on JE in Bangladesh. The vectors of JE—*Culex tritaeniorhynchus* and *Cx. Gelidus*—have been reported to be resistant to DDT (WHO, 1992, WHO, 1998).

2.6.2. Bhutan

There is no official report of JE transmission in Bhutan, though vectors of JE are present in Bhutan. Sporadic cases of JE have also been treated in hospitals, but no epidemic has been reported. There is no report of insecticide resistance in JE vectors in Bhutan.

2.6.3. India

In India, JE was initially reported in the southeastern states of Karnataka, Tamil Nadu and Andhra Pradesh. Since 1973, several other foci of JE from different parts of the country have been reported. In the BBIN region, three districts of West Bengal (along the Indo-Bangladesh border), four districts of Uttar Pradesh (along the Indo-Nepal border), and northeastern states (Assam and Arunachal Pradesh) have reported JE cases with frequent outbreaks. The predominant vectors involved in JE transmission are *Culex tritaeniorhynchus, Cx. vishnui, Cx. pseudovishnui,* and *Cx. gelidus,* but many other species have also been reported as vectors of JE.

There is no separate program for the control of JE, but JE incidence and JE vectors have been monitored since 1978. Indoor spraying of insecticides for malaria is considered as a collateral measure for the control of JE vectors. However, funds for spraying against JE vectors are diverted from the National Antimalaria Program if the area is reported to show a high incidence of JE. Indoor spraying of insecticides in the past has resulted in the development of resistance in JE vectors and varying degrees of resistance to DDT and dieldrin have been reported in different vectors throughout the country (NMEP 1990, 1991, Kulkarni et al. 1992, Singh and Bansal, 1996, Sharma and Kumar, 1996). In the northeastern region, these vectors are still susceptible to DDT and dieldrin (Bhattacharya et al. 1996, Khan et al. 1997).

Though resistance to DDT and dieldrin have been reported throughout the country except in northeastern states, resistance to organophosphates and carbamates have also been reported in *Culex vishnui* from Karnataka (NMEP 1991) and in *Culex triteaniohrhynchus* from Rajasthan. (Bansal and Singh 1996).

2.6.4. Nepal

In Nepal, 2,924 cases of JE and 434 deaths due to it were reported during 1999. Two districts, Bankey and Kailali, reported 71% of the total number of cases. Overall, 18 districts have been reported to be affected by JE with cases being reported throughout the year and epidemics occurring during the rainy season. The major vector of JE, *Culex tritaeniorhynchus,* has been found susceptible to deltamethrin and lambdacyhalothrin, but more information is required on the insecticide resistance in the JE vector and behavior towards different insecticides.

3. Inventory Tables on Insecticide Susceptibility and Resistance

3.1. Susceptibility/resistance status inventory of malaria vectors

3.1. Anopheles aconitus

Country	Locality	Insecticide	Susceptibility/ Resistance Status (% mortality)	Year	Reference
Bangladesh	N.A.	DDT	R	1992	WHO (1992)
	N.A.	DDT HCH	S S	1992	Kondrashin (1992)
	Shalkura-Dhbaura (Mymensingh Dist.)	DDT 4%	R (78–87%)	1995	MPDCU (1995)
Nepal	N.A.	DDT	R	1998	WHO/SEARO (1998)
	N.A.	DDT HCH	R R	1992	Kondrashin (1992)
	N.A.	DDT	R	1992	WHO (1992)

3.2. Anopheles annularis

Country	Locality	Insecticide	Susceptibility/ Resistance Status (R/S % mortality)	Year	References
Bangladesh	N.A.	DDT	R	1992	Kondrashin (1992)
	N.A.	DDT	R	1992	WHO (1992)
	Kamlabari-Jainlapur (Sylhet Dist.)	DDT 4%	R (73%)	1995	MPDCU (1995)
	Mirka-Araihajar (Narayanganj Dist.)	DDT 4%	R (6270%)	1997	MPDCU (1997)
	Lakma-Tahirpur (Sanamganj Dist.)	DDT 4% Malathion 5% Fenitrothion 1%	R/S 90%) S (100%) S (100)	2001	MPDCU (2001)
	N.A.	DDT	R	1998	WHO/SEARO (1998)
India	Koraput (Orissa)	DDT HCH/DLD Malathion Deltamethrin	R (10.3%) R (19.3) S (100%) S (100%)	1990	Sahu et al. (1990)
	Sundergarh (Orissa)	DDT HCH/DLD Malathion Fenitrothion	R (4.4%) R (68.3%) S (100%) S (100%)	1991	Chand & Yadav (1991)
	Cachar (Assam) Nowgaon (Assam) Muzaffarpur (Bihar) SurendraNagar (Gujarat) Indore (Madhya Pradesh)	DDT DDT DDT DLD DLD	R (0%) S (100%) R (65%) R (29.6%) (60%)	1991	NMEP (1991)

	N.A.	DDT HCH	R R	1992 ”	Kondrashin (1992)
	N.A.	DDT	R	1992	WHO (1992)
	Hazari Bagh (Bihar)	DDT DLD Malathion	R (13.1%) R (18.2%) S (100%)	1993	Sharma (1993)
	Bikaner (Rajasthan)	DDT DLD Malathion Fenitrothion Propoxur Permethrin	R (36.2%) R (33.4%) R/S (94.6%) S (100%) R (60.9%) S (98.1%)	1996	Bansal & Singh (1996)
	N.A.	DDT DLD	R R	1996	Pillai (1996)
	Tamulpur (Assam)	DDT	R (82%)	1997	Das et al. (1997)
	N.A.	DDT	R	1998	WHO/SEARO (1998)
	N.A.	Malathion	S	1998	Kumari et al. (1998)
	Bisra Sundargarh (Orissa)	DDT 4% Deltamethrin 0.05%	Standard R (5.8) WHO S (100%) procedure	2000	MRC/STP(2000)
	Raj mahal (Bihar)	DDT Malathion	S (100%) S (100%)	2000	Das et al. (2000)

Nepal	Harpur (Nawalparasi)	Lambdacyhalothrin 1%	R/S/ 80%	1997	Anon. (1997)
	N.A.	DDT	R	1992	WHO (1992)
	N.A.	DDT HCH	R R	1992	Kondrashin (1992)
	Jhalari (Kanchanpur) Guloriya (Kanchanpur) Pipara (Mahottary)	Lambdacyhalothrin 0.1% Malathion (5%) Bendiocarb (0.1%) DDT (4%) Permethrin (.25%) Deltamethrin (0.025%) Lambdacyhalothrin Malathion (5%) Bendiocarb (.1%)	S (100%) S (100%0 S (100%) R (20%) R (58%) R/S (95%) R/S (96%) S (100%) S (100%)	1999	Anon. (2000)
	Thilla (Dhanusa)	DDT (4%) Permethrin (.25%) Deltamethrin (.025%) Lambdacyhalothrin (.1%) Malathion (5%) Bendiocarb (.1%)	R (18%) R (56%) R/S (93%) R/S (95%) S (100%) S (100%)	1999	Anon. (2000)
	Malakheti (Kailali)	Lambdacyhalothrin 0.1% Malathion (5%) Bendiocarb (0.1%)	S (100%) S (100%) S (100%)	2000	Anon. (2000)

	Kanchanpur	Malathion Bendocarb Deltamethrin Lamdacyhalothrin	S (100%) S (100%) S (100%) R/S (97.3%)	2000	EHP (2000)
	N.A.	DDT	R	2000	Bista & Banarjee (2000)

3.3. Anopheles culicifacies

Country	Locality	Insecticide	Susceptibility/ Resistance status (% mortality)	Year	References
Bhutan	N.A.	DDT	R	1992	WHO (1992)
India	Ghaziabad (Uttar Pradesh)	DDT HCH/DLD Malathion Deltamethrin	R (17.8%) R (16.7%) S (100%) S (100%)	1990	Ansari et al. (1990)
	Koraput (Orissa)	DDT DLD Malathion Deltamethrin	R (35%) R (10%) R/S (83.6%) S (96.6%)	1990	Sahu et al. (1990)
	Maharashtra	DDT	R (128 folds since beginning in 1959)	1990	Deobhankar & Palkar (1990)
	Sundergarh (Orissa)	DDT DLD Malathion/Fenitrothion	R (5%) R (9.9%) S (100%)	1991	Chand & Yadav (1991)
	Gujarat, Arunachal Pradesh	Malathion	R	1991	Raghavendra et al. (1991)
	Arunachal Pradesh, Gujarat, Maharastra, Parts of Karnataka Madhya Pradesh, Orissa Tamilnadu	DDT/Dieldrin/Malathion	R (<80%)	1991	NMEP (1991)

	Haryana	Malathion	R/S (95–100%)	1991	NMEP (1991)
	All others state	DDT/Dieldrin Malathion	R S	1991	NMEP (1991)
	N.A.	DDT/HCH/Malathion	R	1992	Kondrashin (1992)
	Haryana	Malathion	Sp. A: S (91.98%) Sp. B:R (34.38%)	1992	Raghavendra et al. (1992)
	N.A.	DDT/Malathion/Fenitrothion Fenthion/Carbamate	R	1992	WHO (1992)
	Hazari Bagh (Bihar)	DDT DLD Malathion	R (37.5%) R (15.3%) S (94.6%)	1993	Sharma (1993)
	Malkangiri (Orissa)	DDT HCH/DLD	R (0–5%) R (0–6.7%)	1995	Sahu & Patra (1995)
	Jodhpur (Rajasthan)	DDT DLD Malathion	R (30%) R (20%) S (100%)	1995	Shukla et al. (1995)
	Surat (Gujarat)	DDT/HCH/Mal.	R	1995	Srivastava et al. (1995)
	Bikaner (Rajasthan)	DDT DLD Propoxur Permethrin Fenitrothion	R (60.6) R (62%) S/R (96.4%) S (98%) S (100%)	1996	Bansal & Singh (1996)

		DDT/DLD/Malathion Cyfluthrin	R S	1996	Yadav et al. (1996)
	N.A.	DDT/DLD/Malathion Carbamate	R R	1996	Pillai (1996)
	in 18 states in 16 states in 8 states	DDT HCH/DLD Malathion	R R R	1996	Sharma (1996)

3.4. Anopheles dirus (An. balabacensis)

Country	Locality	Insecticide	Susceptibility/ Resistance Status (% Mortality)	Year	References
Bangladesh	N.A.	DDT	S	1992	Kondrashin (1992)
	Chaklapunnjee- Chunarughat (Hobiganj Dist.)	DDT 4% Malathion 5%	S (100%) S (100%)	1995	MPDCU (1995)
	Chaklapunnjee- Chunarughat (Hobiganj Dist.)	DDT 4% Malathion 5%	S (100%) S (100%)	1996	MPDCU (1996)
	Chaklapunnjee- Chunarughat (Hobiganj Dist.)	DDT 4% Malathion 5% Deltamethrin 0.025% Permethrin 0.25% Lambdacyhalothrin 0.05%	S (100%) S (100%) S (100%) S (100%) S (100%)	1999	MPDCU (1999)
India	South Mizoram	DDT	S (100%)	1990	Das et al. (1990)
	Tirap (Arunachal Pradesh)	DDT	R/S (91.40%)	1991	NMEP (1991)
	N.A.	DDT	S	1992	Kondrashin (1992)
	Assam	DDT DLD Malathion	S (100%) S (100%) S (100%)	1998	Prakash et al. (1998)

3.5. Anopheles fluviatilis

Country	Locality	Insecticide	Susceptibility/ Resistance (% Mortality)	Year	References
Bhutan	No report available				
India	Koraput (Orissa)	DDT HCH Malathion Deltamethrin	S (95.8%) S (93.3%) S (100%) S (100%)	1990	Sahu et al. (1990)
	N.A.	DDT	R	1992	WHO (1992)
	N.A.	DDT HCH/DLD	R R	1992	Kondrashin (1992)
	Hazari Bagh (Bihar)	DDT DLD Malathion	S (96.4%) S (94.3%) S (100%)	1993	Sharma (1993)
	Malkangiri (Orissa)	DDT HCH	S (100%) R (24–41.9%)	1995	Sahu & Patra (1995)
	Nainital (Uttar Pradesh)	DDT Deltamethrin Lambdacyhalothrin	R (21.6%) S (100%) S (100%)	1999	Sharma et al. (1999)
	11districts in 8 states in 3 states	DDT DLD	R R	1998	Kumari et al. (1998)

	Bisra Sundargarh (Orissa)	DDT 4% Deltamethrin 0.05%	S (100%) S(100%)	2000	MRC/STP(2000)
	Birkera PHC Sundargarh (Orissa)	DDT 4% Malathion 5% Deltamethrin 0.05%	S (100% S (100%) S (100%)	2001	MRC/STP(2001)
	Baster (Madhya Pradesh) Pauri (Uttar Pradesh) Balsore (Orissa)	DDT DLD DDT DLD DDT	R (50%) R (40%) R (50–60%) S (100%) R(25-36%)	2001	NAMP (2001) unpublished data
	N.A.	DDT HCH/DLD	R R	1992	Kondrashin (1992)
Nepal	N.A.	HCH	R	1992	Kondrashin (1992)
	N.A.	DDT	R	1992	WHO (1992)
	Judi (Kavre)	DDT –4% Permethrin – 0.25% Deltamethrin 0.05% Lambdacyhalothrin 0.05% Malathion – 5% Bendiocarb	R/S (80%) R/S (96.25%) S (100%) S (100%) S (100%) S (100%)	1999	Anon. (2000)

	Malaketi (Kaitali)	DDT Permethrin Deltamethrin	R/S (86%) R/S (95%) S (100%)	1999	Anon. (2000)
	Budhabare (Jhapa) Tkhuttepani (Sindhuli)	Lambdacyhalothrin .01% Lambdacyhalothrin 0.1%	R/S (93.33%) R/S (96.67%)	1999	Anon. (2000)
	Gularia (Kanchanpur) Jhalari (Kanchanpur)	DDT - 4% Permethrin - .25% Deltamethrin 0.05%	R/S (85%) R/S (93.75%) S (100%)	S (100%)	Anon. (2000)
	Kheruwa (Morang)	DDT – 4% Permethrin - .25% Deltamethrin - .025% Lambdacyhalothrin - .1% Malathion – 5% Bendiocarb - .1%	R/S (86%) R/S (88%) R/S (93%) S (100%) S (100%) S (100%)	1999	Anon. (2000)
	Kanchanpur	Deltamethrin Lamdacyhalothrin	S (100%) S (100%)	2000	EHP (2000)
		DDT	R	2000	Bista & Banarjee (2000)
	Dharkhola (Karve)	Deltamethrin 0.05% Lambdacyhalothrin 0.05%	S (100%) S (100%)	2000	Anon. 2001

3.6. Anopheles maculatus

Country	Locality	Insecticide	Susceptibility/ Resistance status (% mortality)	Year	References
Bangladesh	Pririnjhri-Lama (Bandarban Dist.)	DDT 4%	R (80%)	2000	MPDCU (2000)
		Deltamethrin 0.025%	S (100%)		
		Malathion 5%	S (100%)		
	Panarbashar Para-Lama (Bandarban Dist.	Permethrin 0.75%	S (100%)	2001	MPDCU (2001)
		Lambdacyhalothrin 0.05%	S (100%)		
		Deltamethrin 0.025%	S (100%)		
		Fenitrothion 1%	R/S (93%)		
		Malathion 5%	S (100%)		
Bhutan	N.A.	DDT	R	1992	WHO (1992)
India	Subausiri (Arunachal Pradesh)	DDT	R/S	1991	NMEP (1991)
	N.A.	DDT	R	1992	WHO (1992)
	N.A.	DDT	R	1992	Kondrashin (1992)
	N.A.	DDT	R	1996	Pillai (1996)
	Arunachal Pradesh	DDT	R/S (40.7–100%)		NAMP (2001)
		DLD	R/S (80–93%)	2001	(unpublished data)
Nepal	N.A.	DDT	R	1992	WHO (1992)

	T. Khutterpani T. Ranibas (Sindhuli) Suranga (Jhapa) T. Ranibas (Sindhuli)	Lambdacyhalothrin -0.1%- Lambdacyhalothrin (0.1%) Deltamethrin(0.25%) Bendiocarb (.1%)	R/S (95%) S (100%) R/S (80%) S (100%) R/S (96%)	1997	Anon. (1997)
	Kanchanpur	Bendiocarb Lambdacyhalothrin Deltamethrin	S (100%) S (100%) S (100%)	2000	EHP (2000)
	N.A.	DDT	R (incipient)	2000	Bista & Banerjee (2000)

3.7. Anopheles minimus

Country	Locality	Insecticide	Susceptibility/ Resistance status (% mortality)	Year	References
Bangladesh	N.A.	DDT/HCH/-Malathion	S	1992	Kondrashin (1992)
India	Tripura	DDT	S (94.8%)	1991	Das et al. (1991)
	Kamang (Arunachal Pradesh)	DDT	S (100%)	1991	NMEP (1991)
	Assam	DDT/DLD	R	1997	Das et al. (1997)
	Sib Sagar and Dibrugarh (Assam) Jalpaiguri (West Bengal)	DDT DDT	R S	1998	Kumari et al. (1998)
	Rajmahal (Bihar)	DDT Malathion	S (100%) S (100%)	2000	Das et al. (2000)
	Lohit (Arunachal Pradesh) Maldah (West Bengal)	DDT DDT	R (87.5%) S (100%)	2001	NAMP (2001)unpublished data
Nepal	N.A.	DDT/HCH/-Malathion.	S (100%)	1992	Kondrashin (1992)

	T. Ranibas Sindhauli	Lambdacyhalothrin 0.1%	S (100%)	1996	Anon. (1996)
	T. Ranibas Sindhauli	Deltamethrin	S (100%)	1997	Anon. (1997)
	Suranya Jhapa	Lambdacyhalothrin 0.1%	R/S (80%)	1997	Anon. (1997)

3.8. Anopheles philippinensis (nivipus)

Country	Locality	Insecticide	Susceptibility/ Resistance status (% mortality)	Year	References
Bangladesh	Gilatoly-Jaintapur (Sylhet Dist.) Kamlabari-Jaintapur (Sylhet Dist.)	DDT 4% DDT 4%	R/S 90% S (100%)	1995	MPDCU (1995)
	Kamalabari-Jaintapur (Sylhet Dist.)	DDT 4% Malathion 5%	R 67% R/S 94%	1996	MPDCU (1996)
	Kamalabari-Jaintapur (Sylhet Dist.)	Deltamethrin 0.025% Lambdacyhalothrin DDT Malathion	S (100%) S (100%) R 75% S (100%)	1997	MPDCU (1997)
	Pririnjhari-Lama (Bandarban Dist.)	Malathion	S (100%)	2000	MPDCU (2000)
	Pririnjhari-Lama (Bandarban Dist.)	Malathion 5%	S (100%)	2001	MPDCU (2001)
India	Tripura	DDT	S (94.8%)	1991	Das et al. (1991)
	Kamang (Arunachal Pradesh)	DDT	S (100%)	1991	NMEP (1991)

	Assam	DDT/DLD	R	1997	Das et al. (1997)
	Sib sagar and Dibrugarh (Assam) Lohit (Arunachal Pradesh) Jalpaiguri (West Bengal)	 DDT DDT DDT	 R R S	 1998 1998 1998	 Kumari et al. (1998)
	Rajmahal (Bihar)	DDT Malathion	S (100%) S (100%)	2000	Das et al. (2000)
	Lohit (Arunachal Pradesh) Maldah (West Bengal)	 DDT DDT	 R (87.5%) S (100%)	 2001	 NAMP (2001) unpublished data

3.9. Anopheles stephensi

Country	Locality	Insecticide	Susceptibility/ Resistance status (% mortality)	Year	Reference
India	Delhi	Deltamethrin	R (under selection)	1991	Kumar et al. (1991)
	Vadodara	DDT/DLD	R (26.6%)/R (9.0%)	1991	NMEP (1991)
	N.A.	DDT/HCH/DLD Organophosphorus	R R	1992	Kondrashin (1992)
	Barmer (Rajasthan)	DDT/DLD Malathion/cyfluthrin	R (55%, 57%) S (96% 100%)	1992	Mathur et al. (1992)
	Banglore (Karnataka)	DDT, DLD Fenitrothion/ Propoxur/ Malathion	R (40–80%) R/S (80–100%)	1992	Baskar & Shetty (1992)
	N.A.	DDT Carbamate Organophosphorus Pyrethroid	R R R R	1992	WHO (1992)
	Goa	DDT/DLD/Malathion	R	1993	Thavaselvam (1993)
	Bikaner (Rajasthan)	DDT/DLD Malathion/Fenitrothion/Propoxur Permethrin	R (40%, 45%) R/S (91.3%, 94.6%, 88.8%) S (100%)	1996	Bansal & Singh (1996)

	Calcutta (West Bengal)	DDT Fenitrothion Fenthion Propoxur Deltamethrin Malathion Fenthion Larvicide Fenitrothion	R (55%) R/S (83.3%) S (100%) R (53.3%) S (100% after 30 mt.) R (61.6) S (100%) R/S (96.6)	1996	Mukhopadhyay et al. (1996)
	Rajasthan	DDT/DLD Malathion Fenitrothion Propoxur Permethrin	R R/S S	1996	Singh & Bansal (1996)
	N.A.	DDT/DLD/Malathion Fenitrothion/Pirimphos- Methyl/carbamate	R	1996	Pillai (1996)
	(34 dists.) in 7 States (27 dists.) in 6 states (8 dists.) in 3 states	DDT DLD+DDT Malathion+DLD+DDT	R R R	1996	Sharma (1996)
	Calcutta (West Bengal)	DDT Fenthion Fenitrothion Propoxur	R (55%) S (100%) R/S (83.3) R (53.3)	1997	Mukhopadhyay et al. (1997)
	Delhi	*B. sphaericus* toxins	R (under selection)	1998	Mittal et al. (1998)
	Jodhpur (Rajasthan)	DDT DLD	R (30–40%) R (20–30%)	1999	Batra et al. (1999)

	Surat (Gujarat)	Deltamethrin 0.05% Cyfluthrin .15% Lambdacyhalothrin 0.05% Malathion 5%	Standard 93.3% WHO 93.3% Procedure 88.3% 51.7%	1999	MRC/STP(1999)
	Wide spread Chennai (Tamil Nadu) Belgaon Dharwad Karnataka	DDT/DLD Malathion	R R	1998	Kumari et al. (1998)
	Jodhpur (Rajasthan)	DDT DLD	R (30–40%) R (20–30%)	1999	Batra et al. (1999)
	Calcutta (West Bengal)	DDT DLD Propoxur Fenitrothion Temephos Malathion Fenthion Fenitrothion	S/R (80%) R (12%) R (24%) S (100%) R/S (88% Larvae) S (100%)	2000	Chakraborti & Tandon (2000)

3.10. Anopheles vagus

Country	Locality	Insecticide	Susceptibility/ Resistance status (% mortality)	Year	References
Bangladesh	No information available.				
India	Car-Nicobar Island	DDT	S	1994	Kumari & Sharma (1994)
	Car-Nicobar Island	DDT 4% Malathion 5% Deltamethrin 0.05% Lambdacyhalothrin 0.05% Propoxur 1%	Standard S (100%) WHO S (100%) procedure S (100%) S (100%) S (100%)	2000	MRC/STP (2000)
	Car-Nicobar Island	DDT Deltamethrin	S S	2001	Das (2001) (unpublished data)

3.11. Anopheles sundaicus

Country	Locality	Insecticide	Susceptibility/ Resistance status (% mortality)	Year	References
Bangladesh	Langura- Kalamakanda (Netrokona Dist.)	DDT 4%	R (25–72%)	1995	MPDCU (1995)
	Shelkura-Dhbawra (Mymensingh Dist.)	DDT 4%	R (67%)	1995	
	Kmalabari-Araihazer (Sylhet Dist.)	DDT 4%	R (67%)	1995	
	Bagadi-Jaintapur (Naryanganj Dist.)	DDT 4% Malathion 5%	R (52%) S (100%)	1997	MPDCU (1997)
	Shachail-Taril (Kishoreganj Dist.)	Deltamethrin 0.025% Lambdacyhalothrin 0.05% DDT 4% Malathion 5%	S (100%) S (100%) R (54%) S (100%)	1997	
	Hospital Para-Lama (Bandarban Dist.)	DDT 4%	R/S (85%)	1997	
	Shilertua- Lama (Bandarban Dist.)	Malathion 5% Fenitrothion 1% Permethrin 0.75% Lambdacyhalothrin 0.05% Deltamethrin 0.025%	R/S (90%) S (100%) S (100%) S (100%) S (100%)	2001	MPDCU (2001)

	Panarbashar Para-Lama (Bandarban Dist.)	DDT 4% Fenitrothion 1% Permethrin 0.25%	R (60%) S (100%) S (100%)	2001	
	Lakma-Tahirpur (Sunamganj Dist.)	DDT 4% Fenitrothion 1% Permethrin 0.75% Lambdacyhalothrin 0.05% Deltamethrin 0.05%	R (80%) S (100%) S (100%) S (100%) S (100%)	2001	

3.2. Susceptibility/resistance status inventory of Phlebotomus argentipes (KA vector) and P. papatasi (Vector of CL)

Country	Vector	Locality	Insecticide	Susceptiblity/Resistance Status (% mortality)	Year	Reference
Bangladesh	*P. argentipes*	N.A.	DDT	S	2000	Choudhury (2000)
India	*P. argentipes*	Patana (Bihar) V. Chandauli Bhojpur (Bihar) V. Mahali Samasti pur (Bihar)	DDT DDT DDT	R/S(86.6–100%) R (40%) R (40%)	1990	Mukhopadhyay et al. (1990)
	P. argentipes	Patna (Bihar) Bhoupur (Bihar) Samastipur (Bihar)	DDT DDT DDT	R/S (86.6–100%) R (40%) S (100%) R (40%)	1990	Mukhopadhyay et al. (1990)
	P.argentipes	Sahabganj (Bihar)	DDT DLD	R (82%) S (100%)	1991	NMEP (1991)
	P. argentipes	N.A.	DDT	R	1992	WHO (1992)
	P. papatasi	N.A.	DDT	R	1992	WHO (1992)

	P. argentipes *P. papatasi*	Patna (unsprayed village) Vaishali sprayed village (six times) Vaishali (sprayed village)	DDT DDT DDT	S (100%) R (15.4%) R (2.9%)	1993	Kaul et al.(1993)
	P. papatasi	Panch Mahal (Gujarat)	DDT DLD	R (18%) R (9.2%)	1993	Thapar et al. (1993)
	P. argentipes	Varanasi	DDT	S	1994	Joshi & Rai (1994)
	P. papatasi	Muzafarpur Begu sarai (Bihar)	DDT	S	1995	Das Gupta et al. (1995)
	P. argentipes	Hoogly (West Bengal)	DDT DLD Malathion	S S (100%) S (100%)	1995	Chandra et al. (1995)
	P. argentipes	South 24 paraganas DDT sprayed areas DDT unsprayed area (West Bengal)	DDT DDT	R/S 82.8% R/S 91.2%	1995	Basak & Tandon (1995)
	P. argentipes *P. argentipes*	North & South 24-Paraganas (West Bengal)	DDT DDT	S (100%) R 0%	1996	Mukhopadhyay et al. (1996)

	P. papatasi	Bikaner (Rajasthan)	DDT DLD Propoxur Malathion Fenitrothion Permethrin	R (79.7) R (62.1) R (64.0) S (98.7) S (100%) S (56.8)	1996	Bansal & Singh (1996a)
	P. argentipes	Pondichery	DDT BHC Malathion Deltamethrin Permethrin Lambdacyhalothrin Bendiocarb	R/S R/S R/S (Based on R LD_{90} value) R R/S S	1999	Amalraj et al. (1999)
	P. papatasi	Pondichery	DDT BHC Malathion Deltamethrin Permethrin Lamdacyhalothrin Bendiocarb	R (16.7%) S R/S R/S R R S	1999	Amalraj et al. (1999)

	P. papatasi	Ghaziabad (Uttar Pradesh) Midnapur (West Bengal)	DDT Dieldrin Malathion Deltamethrin DDT Dieldrin Malathion Deltamethrin	R (16.7%) R (40.6%) R/S (95.0) S (100%) R (75%) R (6.6%) R (58.6%) S (100%)	2000	Dhiman & Mittal (2000)
	P. argentipes	Nainital (Almora) (Uttar Pardesh)	DDT	S (98–100%)	2001	Rao et al (2001)
Nepal	*P. papatasi*	Thilla (Dhansua)	Bendiocarb- .1% Malathion- 5% Lambdacyhalothrin .1%	S (100%) S (100%) R (10%)	1997	Anon. (1997)
	P. argentipes	Thilla (Dhansua)	Lambdacyhalothrin .1% Deltamethrin-.025%	S (100%) R/S (100%)	1997	Anon. (1997)
	P. argentipes	Thilla (Dhanusa)	DDT -4% Permethrin- .25% Deltamethrin .025% Lambdacyhalothrin – .1% Malathion- 5%) Bendiocarb-.1%	R/S (98% R/S (99%) S (100%) S (100%) S (100%)	1999	Anon. (2000)

	P. argentipes	Dhanusa District	Malathion Bendiocarb Deltamethrin Lamdacyhalothrin	S (99.33%) S (100%) S (98.75%) S (99.17%)	2001	EHP (2001)
	P.papatasi	Dhanusa District	Malathion Bendiocarb Deltamethrin Lambdacyhalothrin	S (99.17–100%) S (100%) R/S(95.56–99.3) S (100%)	2001	EHP (2001)

3.3. Susceptibility/resistance status inventory of potential vectors of Japanese Encephalitis

Country	Vector	Locality	Insecticide	Susceptibility/ Resistance (% mortality)	Year	References
Bangladesh	*Cx. gelidus* *Cx. tritaeniorhynchus*	N.A.	DDT	R	1992	WHO (1992)
	Cx. tritaeniorhynchrhynchus *Cx. vishnui*	N.A.	DDT	R	1998	WHO/SEARO (1998)
India	*Cx. tritaeniorhynchus*	Bhav Nagar (Gujarat)	DDT DLD	R (57.1%) R (71.7%)	990	NMEP (1990)
	Cx. vishnui	Mandya (Karnataka)	DDT DLD Malathion	R/S (93.5%) R (54%) S (100%)	1990	NMEP (1990)
	Cx. tritaeniorhynchus	Kurnool Guntoor	DLD DDT	R (42.5%) R (50%)	1991	NMEP (1991)

	Cx. vishnui	Mysore Mandya (Karnataka)	DLD Fenitrothion DDT Malathion Fenitrothion Propoxur	R (58.1%) R (51.2%) R (12.7%) R (20.2%) R (2.5%) R (46.7%)	1991	NMEP (1991)
	Cx. vishnui	Triunchveli (Tamil Nadu)	DLD	R (25.3–44%)	1991	NMEP (1991)
	Cx. tritaeniorhynchrhynchus	Dibrugarh (Assam)	DDT	R (40%)	1991	NMEP (1991)
	Cx. tritaeniorhynchus	Goa	DDT DLD Malathion Fenitrothion Propoxur	R/S S (100%) S (100%) S (100%) S (97.5%)	1991	Kulkarni & Naik (1991)
	Cx. tritaeniorhynchus	Kolar (Karnataka)	DDT DLD Malathion Fenitrothion Propoxur Deltamethrin	R (5%) R (1.6%) S (98.5%) R (12.5%) R (49.5%) R/S (75%)	1992	Kulkarni et al. (1992)

	Cx. vishnui	Kolar (Karnataka)	DDT/DLD Malathion Fenitrothion Propoxur Deltamethrin	R (23.7), R/S (96.6) S (100%) S (98.7) R/S (96.2) R/S (8.0)	1992	Kulkarni et al. (1992)
	Cx. pseudovishnui	Kolar (Karnataka)	DDT DLD Malathion Fenitrothion Propoxur Deltamethrin	R (32.5%) R (8.3%) S (100%) S (100%) R (25%) S (100%)	1992	Kulkarni et al. (1992)
	Cx. gelidus	Kolar (Karnataka)	DDT DLD Malathion Fenitrothion Propoxur Deltamethrin	R (58.3%) S (100%) S (100%) S (100%) S (100%) R/S (94.5%)	1992	Kulkarni et al. (1992)
	Cx. gelidus *Cx. tritaeniorhynchus*	N.A. N.A.	DDT DDT	R R	1992 1992	WHO (1992) WHO (1992)
	Cx. tritaeniorhynchus and Cx. fuscocephala	Mysore (Gujarat)	Temephos, Fenthion, Malathion, Fenitrothion, Deltamethrin, Cypermethrin	*Cx .tritaeniorhynchus* more tolerant than *Cx. fuscocephala* to all larvicides	1993	Vijayan et al. (1993)

	Cx. tritaeniorhynchus	Bikaner (Rajasthan)	DDT DLD Malathion Fenitrothion Propoxur Permethrin	R (77.3%) R (62.1%) S (100%) S (100%) R/S (97.4%) S (100%)	1995	Bansal & Singh (1995)
	Cx. pseudovishnui	Bikaner (Rajasthan)	DDT DLD Malathion Fenitrothion Propoxure Permethrin	R/S (87.2%) R (77.4%) S (100%) S (100%) S (100%) S (100%)	1995	Bansal & Singh (1995)
	Cx. tritaeniorhynchus	Dibrugarh (Assam)	DDT DLD Malathion	S (98.7%) S (100%) S (100%)	1996	Bhattacharya et al. (1996)
	Cx. vishnui *Cx. pseudovishnui* *Cx. fuscocephala*	Dibrugarh (Assam)	DDT DLD Malathion	S (100%) S (100%) S (100%)	1996	Bhattacharya et al. (1996)
	Ma. uniformis	Dibrugarh	DDT DLD Malathion	S (98%) S (99%) S (100%)	1996	Bhattacharya et al. (1996)

	Cx. tritaeniorhynchus	Kota (Rajasthan)	DDT DLD Malathion Fenitrothion Propoxur Permethrin	R R R R/S Based on R LC_{95} value S	1996	Singh & Bansal (1996a,b)
	Cx. tritaeniorhynchus	Haryana	DDT DLD Malathion	R (66.66%) R (65%) S (100%)	1996	Sharma & Kumar (1996)
	Mansonia annulifera & *Ma. uniformis*	Dibrugarh (Assam)	DDT DLD Malathion	S (100%) S (100%) S (100%)	1997	Khan et al. (1997)
	Cx. tritaeniorhynchus	Warangal Chittoo (Andhra Pradesh)	Malathion DDT	R (13–60%) R (15%)	2001	NAMP (2001) unpublished data
	Cx. tritaeniorhynchus	Kanchanpur district	Deltamethrin Lambdacyhalothrin	S (100%) S (100%)	2001	EHP (2001)

4. Summary and Conclusions

1. Insecticides continue to play an important role in the control of malaria and other vector-borne diseases in BBIN countries. The type of insecticide and the application strategy differ from country to country and vector to vector, depending on the susceptibility/resistance and behavior of the vector populations.

2. DDT is still being used in the control of malaria and KA in most parts of India, while its use in Nepal, Bangladesh, and Bhutan has been banned completely since 1990, 1994 and 1995, respectively. In Bangladesh however, some DDT is being used against the KA vector, and malathion is being used for indoor spraying against malaria vectors and deltamethrin for the treatment of mosquito nets. In Bhutan, deltamethrin has been used for indoor spraying as well as for the impregnation of mosquito nets for the past four to five years. In Nepal, malathion, pirimiphos-methyl, bendiocarb, and lambdacyhalothrin have been used for indoor spraying in selected areas. Recently deltamethrin has also been introduced for indoor spray and impregnation of mosquito nets.

3. Twelve Anopheline species have been reported as malaria vectors in Bangladesh, Bhutan, India and Nepal (BBIN), but all are not directly involved in cross-border malaria transmission.

4. Based on current information, two major vectors of malaria in BBIN countries that are implicated in cross-border malaria transmission—*An. minimus* and *An. Dirus*—are fully susceptible to DDT and all other insecticides used so far in the control of malaria. While susceptible to DDT and other insecticides, these two species have developed behavioral resistance to DDT due to its tendency to repel them, and they prefer to rest outdoors, thus avoiding contact with DDT for a duration that is required to kill them. However *An. minimus* and *An. dirus* have been reported from indoor collection in certain unsprayed areas in Assam and Arunachal Pradesh in India. After the introduction of synthetic pyrethroids, *An. minimus* has almost disappeared from Nepal.

5. Another important vector in cross-border transmission, *An. fluviatilis,* has become resistant to DDT and dieldrin/HCH, but it is susceptible to all the other insecticides used for malaria control in Nepal. *An. fluviatilis* is still susceptible to DDT in some parts of Orissa in India, but no report of its resistance is available from Bhutan. Recently *An. fluviatilis* has been shown to be a complex of three sibling species, S, T and U. Of these species, S is a highly anthropophagic and persistent malaria vector in Orissa, while sp. T, prevalent in Uttar Pradesh Terai, is a poor vector and has been reported to be resistant to DDT.

6. *An. culicifacies s.l.*, the major vector of malaria in most parts of India and also a suspected vector in Nepal, has developed widespread resistance to DDT and dieldrin/HCH and also against malathion in several districts in India. Recent reports have shown reduced susceptibility to deltamethrin in *An. culicifacies* populations in the Rameshwaram Islands (southern India) and resistance to deltamethrin in Surat district (Gujarat state) in field populations. Though *An. culicifacies* is not directly responsible for cross-border malaria transmission, it is the number one vector species in most parts of India and is indirectly responsible for malaria transmission in BBIN countries through migratory populations. *An. culicifacies* in India has been reported to be a complex of five sibling species: A, B and C, D and E. Susceptibility of these sibling species to insecticides as well as to malaria parasites differs like that of two different species. Resistance to DDT in sibling sp. B, which is a poor malaria vector, has been reported to build up faster than the sympatric population of sibling sp. A, which is a persistent malaria vector. Spraying of DDT in such areas thus has an epidemiological impact on malaria transmission. Similar observations can be made with regard to malathion: sp. A is still susceptible to it and sp. B and C that have become resistant to it in certain parts of India. It has now been concluded that species C (a vector) develops resistance to insecticide at a faster rate than sp. B and that sp. B (non-vector) develops resistance faster than sp. A (vector). Species C has developed resistance to most of the insecticides used for malaria control, while sp. A is still susceptible to malathion and synthetic pyrethroids and only partially resistant to DDT and dieldrin.

7. *An. philppinensis,* a vector of malaria in Bangladesh and India, has also been reported to be resistant to DDT and dieldrin in India, but there is no report of its resistance to other insecticides.

8. *An. annularis,* a secondary vector of malaria in India and a major vector in Nepal, has been reported to be resistant to DDT and dieldrin/HCH in both the countries. It has also been shown to have reduced susceptibility to malathion in Rajasthan in India and lambdacyhalothrin in Nepal.

9. *An. sundaicus*, a malaria vector in the delta region of Bangladesh and the Andaman and Nicobar Islands in India is also fully susceptible to DDT, but this species has also been reported in outdoor resting collection in the Car-Nicobar Islands.

10. *An. Maculates,* a vector of malaria in Nepal and Bhutan, a suspected vector in Bangladesh, and a non-vector in India, has also developed resistance to DDT, but there is no report of its resistance to other insecticides.

11. *An. stephensi* type form, another major vector of malaria in urban areas of India but not a vector in other BBIN countries, has also been reported to be resistant to DDT and dieldrin in different parts of India, although these insecticides are not used for indoor spraying in urban areas. *An. stephensi* also is not directly involved in cross-border malaria transmission but is indirectly involved in malaria transmission through a migratory population. *An. stephensi* exists in three different varieties: the type form, Mysorensis, and Intermediate. Only the type form, which has been reported to breed

in contained waters in tanks in urban areas, is a vector, while Mysorensis, a surface breeder in rain water collection in rural areas, has not been implicated as a vector. In rural areas *An. stephensi* has become resistant to DDT, HCH, and also malathion to some degree. In urban areas, where control strategy is based on antilarval methods, *An. stephensi* is fairly susceptible to commonly used larvicides, notwithstanding scattered reports of resistance to temephos. *An. stephensi* larvae have been shown to develop resistance to almost all the groups of insecticides (including microbial toxin of *Bacillus sphaericus)* under selection.

12. *An. aconitus,* reported as malaria vector in Bangladesh and Nepal, has also developed resistance to DDT and HCH/dieldrin, but there is no report of resistance to other insecticides used for malaria control in these countries.

13. There is very little information about the insecticide resistance in *An. varuna* and *An. jeyporiensis,* which are reported as secondary vectors of malaria in India. Though resistance to DDT in *An. varuna* has been reported, there is no report of resistance to any other insecticide in this species. Similarly, there is no information of insecticide resistance in *An. jeyporiensis.*

14. In addition to twelve anopheline species reported as malaria vectors in BBIN countries, *An. subpictus* has been implicated in some coastal villages of southern India and Bastar district, Madhya Pradesh in India. This species is a prolific breeder in rainwater collection throughout India and has been reported to be resistant to DDT and dieldrin. Recent reports have shown *An. vagus* also as a malaria vector in Bangladesh, where it has also been reported to be resistant to DDT.

15. KA is another major vector-borne disease in BBIN countries with high risk of cross-border transmission. It is transmitted by a sandfly vector, *Phlebotomus argentipes*. This species has been shown to be resistant to DDT in areas of KA transmission in Bihar. However, it is still susceptible to DDT in Bangladesh and West Bengal in India. In Pondicherry, southern India, where KA is not a problem, *P. argentipes* has also been reported to be resistant to permethrin and tolerant to DDT and malathion. Another species of sandfly *P. papatasi,* which is not a vector of KA but causes cutaneous leishmaniases, has been reported to have developed a high degree of resistance to DDT and dieldrin in different areas. In Nepal, both *P. argentipes* and *P. papatasi* are reported as susceptible to malathion, bendiocarb, and synthetic pyrethroid.

16. Japanese encephalitis (JE) is also an important vector-borne disease in BBIN countries and is transmitted by *Culex vishnui* group of mosquitoes: *Cx. tritaeniorhynchus, Culex vishnui*, *Cx. pseudovishnui,* and some other species such as *Culex gelidus, Mansonia annulifera* and *Ma. Uniformis.* Most of these species have been reported to be resistant to DDT and dieldrin in most parts of India with Assam a notable exception. Most of these species are exophilic, and therefore the insecticides used for indoor spraying are not effective for the control of JE vectors. *Cx. tritaeniorhynchus* and other JE vectors are susceptible to malathion in most of the areas in India, but in some areas, resistance to malathion has also been reported. In

Nepal, *Cx. tritaeniorhynchus* is susceptible to synthetic pyrethroids, which are being used for indoor spraying.

5. Recommendations for Follow-up Activities

There is a need for information exchange and networking between and among different countries of the BBIN region on insecticide resistance data to tackle the resistance problem at the regional level and to establish research priorities in this area.

Currently, reports of susceptibility tests are sent to WHO/SEARO and WHO Headquarters, where they are entered into a database. The information from Nepal, Bhutan and Bangladesh is very sketchy, and thus there is a need for more data on insecticide resistance in malaria, KA and JE vectors particularly from Bangladesh, Nepal and Bhutan.

Systematized information on insecticide resistance in vectors from areas under the continuous spray of the same insecticide vis-a-vis areas without and with alternative insecticides should be generated, in order to assess the magnitude of resistance under different spraying conditions.

More information is required on vector behavior, vector implication, and vector resistance in the bordering areas as a result of changing ecology and the use of insecticides.

There is a lack of data pertaining to the mechanisms of insecticide resistance in different vector species. Such data would address the problem of cross-resistance/multiple resistance to different insecticides.

5.1. Recommendations for spray strategy to control resistant vectors

In areas where more than one vector is involved in transmission and one vector is susceptible, while another or others have become resistant to a particular insecticide, a change in insecticide may be required, depending upon the primary or secondary role of the resistant vector species. Where the primary vector is susceptible and the secondary vector is resistant, no change is required. If the primary vector is resistant and the secondary vector is susceptible, a change in insecticide is recommended. However, if the primary vector is still susceptible to a particular insecticide but has become exophilic due to its excito-repellency, a change in control strategy is recommended. Mosquito nets treated with synthetic pyrethroid, which have a knockdown effect, should be used in areas with predominantly anthropophagic vectors.

5.2. Recommended spray strategy to control An. culicifacies

Since *An. culicifacies* is a complex of five sibling species with different vectorial potential and susceptibility to insecticides, a specific strategy to control *An. culicifacies* as given in Table 2 has been recommended by Subbarao and Sharma (1997).

Table 5.1. Responses of sibling species to insecticides and recommended spray strategy1 to control *An. culicifacies*

Species **Vector status**	**A** **Vector**	**B2** **Non-vector**	**C** **Vector**
1. DDT			
Rate of development of resistance	Slow	Fast	Fast
Susceptibility status in areas where insecticide has been withdrawn	Moderate 30-60%	Low < 10%	Low < 10 %
Spraying strategy	Recommended[3]	Not required	Not recommended
2. BHC			
Rate of development of resistance	Fast	Fast	Fast
Susceptibility status in areas where insecticide has been withdrawn	Low <5%	Low < 5%	Low < 5%
Spraying strategy	Not recommended	Not required	Not recommended
3. MALATHION-4			
Rate of development of resistance	Slow 9–10 years	Intermediate 6–7 yrs.	Fast 4–5 yrs.
Development of resistance due to usage in agriculture	No evidence	Yes	Yes
Spraying strategy	Recommended	Not required	Recommended—if susceptible to Malathion
4. CARBAMATES/ Synthetic pyrethroids			
Susceptibility	High	High	High
Development of resistance due to usage in agriculture	No evidence	No evidence	No evidence

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Annex 1.

Insecticide usage in Malaria Control Program (including KA and JE) in the Bangladesh, Bhutan, India and Nepal Region from 1990 - 1996

Country	Insecticide in metric ton	1990	1991	1992	1993	1994	1995	1996
Bangladesh	DDT (75% wdp)	644	222	644.7	223.9	109.6*	137.4*	50.6*
	Malathion (25% wdp)	0	0	0	0	4.2	2.1	N.A.
	Deltamethrin (25% EC)	0	0	0	0	1.0	0.6	0.4
Bhutan	DDT (75%wdp)	20	0	1.6	0	1.0	0	0
	Deltamethrin (2.5% wp)	0	0	0	0	0	4.4	3.0
	Temephos							
	Fenthion (EC)	0.04	0	0	0	0	0	0
	Diazinon	0.2	0	0	0	0	0	0
India	DDT (75% wdp)	11200	773.5	8000	5367	8180	8998	1080
	HCH (50% wdp)	7600	8999	10000	5954.6	5450	5784	7600

	Malathion (25% wdp)	2200	1764	2700	1122.4	720	368	300
	Temephos (EC)	2140	0	0	2760	2370	3200	3030
	Fenthion (EC)	4061	0	0	6330	6000	7220	7080
Nepal	DDT (75% wdp)	0	N.A.	N.A.	N.A.	0	0	0
	Malathion (50% wdp)	77.7	N.A.	350	64.7	81.4	N.A.	2.25
	Bendiocarb (80% wdp)	6.8	6.1	0.36	0.1	N.A.	N.A.	0
	Pirimiphos-methyl (50 EC)	59.0	N.A.	N.A.	N.A.	N.A.	N.A.	0
	Lamdacyhalothrin (10% wdp)	0.2	N.A.	7.6	1.5	4.1	N.A.	9.52

Source: WHO/SEARO (1998) Insecticide resistance in mosquito vectors of disease SEA/VBC/59 used for KA

Annex 2.

Insecticides used in the control of malaria and KA in Bangladesh, Bhutan and Nepal from 1997-2000

Country	Insecticide used	1997	1998	1999	2000
Bangladesh	DDT 75% wdp (IRS)	N.A.	N.A.	45,338 kg (34,004 kg ai)	39,990 (29,932.5 kg ai)
	Malathion 57% EC (IRS)	N.A.	N.A.	4,039 L (2,302.2 L ai)	2,581L (1,471. L ai)
	Deltamethrin 2.5% EC (ITMN)	N.A.	N.A.	3,000L (75 L ai)	3,000L (75 L ai)
Bhutan	DDT	0	0	0	0
	Deltamethrin 2.5 wp (IRS)	8,900 kg (222.5 kg ai)	0	0	0
	Temephos (50% EC)	0	267 L (133.5 L ai)	N.A.	N.A.
	Bti (wp)	0	3,161 L	300 L	N.A.

Nepal	Malathion (50% wp)	1,476 kg (738 ai)	0	0	0
	S-P (ICON 10% wp)	4,832.4 (483.2 ai)	2,446.75 (244.67 ai)	7,972.7 797.27 ai)	253 (25.3 ai)
	S-P (K-Othrine 2.5% WP)	0	0	0	29016.78 (725.4 ai)

ai = active ingredients
Kg = Kilogram
L = Liter
S-P = Synthetic pyrethroid

Annex 3.

Insecticides used in control of malaria and KA in India from 1991-2000

Year	Compound	Formulation	Concentration	Type of application	To control	Amount of formulation
1991	DDT	WP	50%	Indoor Residual Spraying	Malaria	11,729,000 Kg
1991	BHC	WP	50%	Indoor Residual Spraying	Malaria	584,935 Kg
1991	Malathion	WP	25%	Indoor Residual Spraying	Malaria	425,000 Kg
1992	DDT	WP	50%	Indoor Residual Spraying	Malaria	6,077,00 Kg
1992	BHC	WP	50%	Indoor Residual Spraying	Malaria	524,875 Kg
1992	Malathion	WP	25%	Indoor Residual Spraying	Malaria	25,000 Kg
1993	DDT	WP	50%	Indoor Residual Spraying	Malaria	6,248,500 Kg
1993	BHC	WP	50%	Indoor Residual Spraying	Malaria	7,479,000 Kg
1993	Malathion	WP	25%	Indoor Residual Spraying	Malaria	Zero
1994	DDT	WP	50%	Indoor Residual Spraying	Malaria	8,302,000 Kg
1994	BHC	WP	50%	Indoor Residual Spraying	Malaria	6,305,000 Kg
1994	Malathion	WP	25%	Indoor Residual Spraying	Malaria	700,000 Kg
1995	DDT	WP	50%	Indoor Residual Spraying	Malaria	10,897,000 Kg
1995	BHC	WP	50%	Indoor Residual Spraying	Malaria	7,584,000 Kg
1995	Malathion	WP	25%	Indoor Residual Spraying	Malaria	87,500 Kg
1996	DDT	WP	50%	Indoor Residual Spraying	Malaria	8,206,000 Kg

1996	BHC	WP	50%	Indoor Residual Spraying	Malaria	3,204,000 Kg
1996	Malathion	WP	25%	Indoor Residual Spraying	Malaria	224,000 Kg
1997	DDT	WP	50%	Indoor Residual Spraying	Malaria	8,542,000 Kg
1997	DDT	WP	50%	Indoor Residual Spraying	KA	3,600,000 Kg
1997	BHC	WP	50%	Indoor Residual Spraying	Malaria	8,400,000 Kg
1997	Lindane	WP	50%	Indoor Residual Spraying	Malaria	1,680,000 Kg
1997	Malathion	WP	25%	Indoor Residual Spraying	Malaria	16,200,000 Kg
1997	Synthetic pyrethroid Deltamethrin Cyfluthrin Lambdacyhalothrin	WP	? 2.5% 10% 10%	Indoor Residual Spraying	Malaria	 108,800 Kg 35,000 Kg 35,000
1997	Flocw Synthetic Pyrethroid Deltamethrin Cyfluthrin	 SC EW	? 2.5% 5%	Insecticide Treated Nets	Malaria	17,000 Kg
1998	DDT	WP	50%	Indoor Residual Spraying	Malaria	
1998	DDT	WP	50%	Indoor Residual Spraying	KA	3,000,000 Kg
1998	BHC	WP	50%	Indoor Residual Spraying	Malaria	3,360,000 Kg
1998	Lindane	WP	50%	Indoor Residual Spraying	Malaria	3,360,000 Kg
1998	Malathion	WP	25%	Indoor Residual Spraying	Malaria	16,200,000 Kg

1998	Synthetic pyrethroid Deltamethrin Cyfluthrin Lambdacyhalothrin	WP	? 2.5% 10% 10%	Indoor Residual Spraying	Malaria	 221,000 Kg 70300 Kg 44900 Kg
1998	Flocky Synthetic pyrethroid Deltamethrin Cyfluthrin	 SC EW	 2.5% 5%	Insecticide Treated Nets	Malaria	50,000 L
1999	DDT	WP	50%	Indoor Residual Spraying	Malaria	6,500,000 Kg
1999	DDT	WP	50%	Indoor Residual Spraying	KA	2,000,000 Kg
1999	Lindane	WP	50%	Indoor Residual Spraying	Malaria	6,720,000 Kg
1999	Malathion	WP	25%	Indoor Residual Spraying	Malaria	16,200,000 Kg
1999	Synthetic pyrethroid Cyfluthrin Lambdacyhalothrin Alpha cypermethrin	WP	 2.5% 10% 5%	Indoor Residual Spraying	Malaria	 59,400 Kg 71,900 Kg 146,900 Kg
1999	Flocky Synthetic pyrethroid Deltamethrin Cyfluthrin	 SC EW	 2.5% 5%	Insecticide treated Nets	Malaria	120,000 Kg
2000	DDT	WP	50%	Indoor Residual Spraying	Malaria	6,000,000 Kg
2000	DDT	WP	50%	Indoor Residual Spraying	KA	2,000,000 Kg
2000	Lindane	WP	50%	Indoor Residual Spraying	Malaria	6,720,000 Kg

2000	Malathion	WP	25%	Indoor Residual Spraying	Malaria	16,200,000 Kg
2000	Synthetic pyrethroid Deltamethrin Lambdacyhalothrin Cyfluthrin Alpha cypermethrin	WP	 2.5% 10% 10% 5%	Indoor Residual Spraying		 169,000 Kg 34700 Kg 41250 Kg 70,600 Kg
2000	Flocky Synthetic pyrethroid Deltamethrin Cyfluthrin	 SC EW	 2.5% 5%	Insecticide Treated Nets	Malaria	172,000 Kg
2001	DDT	WP	50%	Indoor Residual Spraying	Malaria	3,000,000 Kg
2001	DDT	WP	50%	Indoor Residual Spraying	KA	4,000,000 Kg
2001	Lindane	WP	50%	Indoor Residual Spraying	Malaria	6,720,000 Kg
2001	Malathion	WP	25%	Indoor Residual Spraying	Malaria	16,200,000 Kg
2001	Synthetic pyrethroid Deltamethrin Cyfluthrin Lambdacyhalothrin	WP	 2.5% 10% 10%	Indoor Residual Spraying	Malaria	2,880,000 Kg
2001	Flocky Synthetic pyrethroid Deltamethrin Cyfluthrin	 SC EW	 2.5% 5%	Insecticide Treated Nets	Malaria	172,000 Kg

Year	Compound	Formulation	Concentration	Type of application	For control of	Amount of formulation used
1997	Fenthion	EC	82.5%	Larvicide	Filariasis and Mosquito	150,000 L
1997	Temephos	EC	50%	Larvicide	Malaria	100,000 L
1997	Malariol	Oil	-	Larvicide	Mosquito	1,600,000 L
1998	Fenthion	EC	82.5%	Larvicide	Filariasis and Mosquito	150,000 L
1998	Temephos	EC	50%	Larvicide	Malaria	100,000 L
1998	Malariol	Oil	-	Larvicide	Mosquito	1,600,000 L
1998	Pyrethroid	Extract	-	Space spray	Mosquito	17,500 L
1999	Fenthion	EC	82.5%	Larvicide	Filariasis and Mosquito	150.000 L
1999	Temephos	EC	50%	Larvicide	Malaria	100,000 L
1999	Malariol	Oil	-	Larvicide	Mosquito	1,600,000 L
1999	Pyrethroid	Extract	-	Space Spray	Mosquito	20,000 L
2000	Fenthion	EC	82.5%	Larvicide	Filariasis and Mosquito	150,000 L
2000	Temephos	EC	50%	Larvicide	Malaria	100,000 L
2000	Malariol	Oil	-	Larvicide	Mosquito	1,600,000 L
2000	Pyrethroid	Extract	-	Space Spray	Mosquito	20,000 L
2001	Fenthion	EC	82.5%	Larvicide	Filariasis and Mosquito	150,000 L
2001	Temephos	Ec	50%	Larvicide	Malaria	100,000 L

2001	Malariol	Oil	-	Larvicide	Mosquito	1,600,000 L
1997						
1997						
1997						
1997						
1997						
1997	Synthetic pyrethroid Deltamethrin Cyfluthrin Lambdacyhalothrin	WP	 2.5% 10% 10%	Indoor Residual Spraying	Malaria	 108,800 Kg 35,000 Kg 35,000
1997	Flocky Synthetic Pyrethroid Deltamethrin Cyfluthrin	 SC EW	 2.5% 5%	Insecticide Treated Nets	Malaria	17,000 Kg
1998	DDT	WP	50%	Indoor Residual Spraying	Malaria	
1998	DDT	WP	50%	Indoor Residual Spraying	KA	3,000,000 Kg
1998	BHC	WP	50%	Indoor Residual Spraying	Malaria	3,360,000 Kg
1998	Lindane	WP	50%	Indoor Residual Spraying	Malaria	3,360,000 Kg
1998	Malathion	WP	25%	Indoor Residual Spraying	Malaria	16,200,000 Kg

1998	Synthetic pyrethroid Deltamethrin Cyfluthrin Lambdacyhalothrin	WP	 2.5% 10% 10%	Indoor Residual Spraying	Malaria	 221,000 Kg 70300 Kg 44900 Kg
1998	Flocky Synthetic pyrethroid Deltamethrin Cyfluthrin	 SC EW	 2.5% 5%	Insecticide Treated Nets	Malaria	50,000 L
1999	DDT	WP	50%	Indoor Residual Spraying	Malaria	6,500,000 Kg
1999	DDT	WP	50%	Indoor Residual Spraying	KA	2,000,000 Kg
1999	Lindane	WP	50%	Indoor Residual Spraying	Malaria	6,720,000 Kg
1999	Malathion	WP	25%	Indoor Residual Spraying	Malaria	16,200,000 Kg
1999	Synthetic pyrethroid Cyfluthrin Lambdacyhalothrin Alpha cypermethrin	WP	 2.5% 10% 5%	Indoor Residual Spraying	Malaria	 59,400 Kg 71,900 Kg 146,900 Kg
1999	Flocky Synthetic pyrethroid Deltamethrin Cyfluthrin	 SC EW	 2.5% 5%	Insecticide treated Nets	Malaria	120,000 Kg
2000	DDT	WP	50%	Indoor Residual Spraying	Malaria	6,000,000 Kg
2000	DDT	WP	50%	Indoor Residual Spraying	KA	2,000,000 Kg
2000	Lindane	WP	50%	Indoor Residual Spraying	Malaria	6,720,000 Kg

2000	Malathion	WP	25%	Indoor Residual Spraying	Malaria	16,200,000 Kg
2000	Synthetic pyrethroid Deltamethrin Lambdacyhalothrin Cyfluthrin Alpha cypermethrin	WP	 2.5% 10% 10% 5%	Indoor Residual Spraying		 169,000 Kg 34700 Kg 41250 Kg 70,600 Kg
2000	Flocky Synthetic pyrethroid Deltamethrin Cyfluthrin	 SC EW	 2.5% 5%	Insecticide Treated Nets	Malaria	172,000 Kg
2001	DDT	WP	50%	Indoor Residual Spraying	Malaria	3,000,000 Kg
2001	DDT	WP	50%	Indoor Residual Spraying	KA	4,000,000 Kg
2001	Lindane	WP	50%	Indoor Residual Spraying	Malaria	6,720,000 Kg
2001	Malathion	WP	25%	Indoor Residual Spraying	Malaria	16,200,000 Kg
2001	Synthetic pyrethroid Deltamethrin Cyfluthrin Lambdacyhalothrin	WP	 2.5% 10% 10%	Indoor Residual Spraying	Malaria	2,880,000 Kg
2001	Flocky Synthetic pyrethroid Deltamethrin Cyfluthrin	 SC EW	 2.5% 5%	Insecticide Treated Nets	Malaria	172,000 Kg

Source: Dr. V.P. Sharma, SEARO (WHO)

Annex 4.

State-wise/district-wise information on the use of various insecticides in India

States	DDT 1	BHC 2	Malathion 3	Synthetic pyrethroid 4
				Deltamethrin/ Cyfluthrin/ Lamdacyhalothrin
Andhra Pardesh	All districts (Except column 2)	-	-	-
Assam	All districts (except Karbi Anglong)	-	-	-
Arunachal Pardesh	All districts	-	-	-
Bihar	All districts	-	-	-
Gujarat	All districts except in column 3	-	Surendranagar, Agreli, Junagarh, Banaskantha, Mehsana, Panch Mehal, Bharuch and Valsal	-
Haryana	-	All districts except in column 3	-	Deltamethrin and Cyfluthrin in Mewat region since 1997

Himachal Pardesh	DDT only focal spray except in column 2	Sirmaur, Solan	-	-
Jammu and Kashmir	Doda, Jammu, Kathna, Poonch, Udhampur and Rajori	-	-	-
Karnataka	All districts except column 3		Bijapur, Chitrodurga, Gulparga and Raidur	Deltamethrin and Cyfluthrin in a few districts
Kerala	Focal spray	-	-	-
Maharashtra	All districts except column 3	-	Dhula	Deltamethrin, Cyfluthrin in some areas
Madhya Pradesh	21 districts	All districts except in column 1	-	-
Nagaland	All districts	-	-	-
Orissa	All districts except column 2	Keonjhar, Koraput Mayur Bhauj	-	-
Punjab	All districts except in column 2 and 3	Ferojpur, Faridkot, Fatehgarh Saheb, Mansa (Patiala Sanyram partially)	Patiala, Sangrur	-
Rajasthan	All districts except in column 2	Ganga Nagar, Jhunjhunu, Alwar, Bhatpur, Dholpur, Barmer, Jalore, Udaupur, Chittorgarh and Dhangarpur	-	-
Sikkim	All districts	-	-	-
Manipur	All districts	-	-	-
Meghalya	All districts except non-malaria area	-	-	-
Tamil Nadu	-	-	-	-

Uttar Pradesh	All districts except column 2 and those in the Himalayan Region	-	Dharmapuri, Thiruvanamalti, Ram, Nathpuram	-
Goa	Focal spray	-	-	-
West Bengal	All districts except column 2	Midnapore, Benkura, Purulia	-	-
Andaman and Nicobar	All districts	All areas	-	-
Dadra and Nagar Haveli	-	-	-	-
Lakshdweep	Focal spray	-	-	-
Pondichery	All areas	-	Focal spray	-

Source: Shiv Lal et al. 1998 .

Annex 5.

Catalog of institutions and individuals involved in insecticide resistance studies in BBIN

Bangladesh

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STP-RBM

South East Asia Regional Office

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Dr. M.K. Banerjee

STP-RBM

South East Asia Regional Office

World Health Organization

Mahatma Gandhi Marg

New Delhi-110002 INDIA

Contact addresses of institutions and individuals referred to in the text

Country	Institutions	Name of Individuals	Date of Report
Bangladesh	Malaria and Parasitic Disease Control Unit (MPDCU), Directorate General of Health Services, Mohakhali Dhaka – 1212 BANGLADESH	Bengali, A.M. MPDCU	2000 1995, 1996,1997, 1999, 2000, 2001
	Epidemic Control Preparedness Program ICDDRB, GPO Box 128 Dhaka - 1000 BANGLADESH	Dr. S. Choudhary	2000
Bhutan	National Malaria Control ProgramPublic Health Division Department of Health GELEPHU: BHUTAN, Tel.: 975-6-251133, 251012, 251115, 251461 E-mail: nmcp@druknet. Net.bt. NMCP - Bhutan	Anonymous	2000

India	Directorate of National Anti-Malaria Programme Directorate General of Health Services Ministry of Health and Family Welfare, Govt. of India 22- Sham Nath Marg, Delhi – 110054 (NAMP-DELHI)	Dhillon, G.P.S. Joshi, R.D. Kaul, S.M. Kumari, R. Rao, J.S. Saxena, N.B.L. Sharma, S.N. Sharma, R.S. Shiv Lal Thapar, B.R. Sonal G.S. Narsimhim, M.V.V.L Das Gupta, R.K. Yadav, R.L.	1996,1998 1994, 1995 1998, 1993, 1994 1994, 1998 1993, 1996, 1995 1995, 1996, 1990, 1996a, 1993 1993, 1996 1995, 1999, 1994 1998, 1998a 1998, 1993 1998 1993, 1990 1993,1995, 1998 1996
	Malaria Research Centre (Indian Council of Medical Research) 22 - Sham Nath Marg Delhi - 110054 (MRC – DELHI)	Ansari, M.A. Adak T. Batra, C.P. Chand, S.K. Dhiman, R.C. Joshi H. Kumar, A. Mittal, P.K. Nanda Nutan Pandey, A.C.	1990 1998, 1999, 2002, 1990, 1999 1991 2000, 2001 2000 1993 1990, 1998, 1999, 2000, 2002a,2002b 2000, 2002 1995

		Raghavendra, K.	1991, 1992, 1997, 1999, 2002a,2002b
		Razdan, R.K.	1990
		Sharma, V.P.	1990,1991,1992,1995,1996,1998,1999
		Sharma, S.N.	1999
		Shukla, R.P.	1999,1995
		Singh, O.P.	2002a, 2002b
		Srivastva, H.C.	1995
		Subbarao, S.K.	1991, 1992,1997, 1998, 2002a, 2002b
		Sumodan, P.K.	1993
		Thaveselvam, D.	1993
		Vasantha, K.	1991
		Yadav, R.S.	1991, 2000
		Pillai, C.R.	2001
	Regional Medical Research Centre	Narain, K.	1997
	(Indian Council of Medical Research)	Khan, S.A.	1997
	Dibrugarh - 786001, Assam	Prakash, A.	1996, 1998, 1996a
	(RMRC – DIBRUGARH)	Bhattacharya, D.	1996,1998, 1996a
		Mahanta, J.	1996, 1998, 1996a
		Mahapatra, J.	1996, 1998
		Dutta, P.	1996, 1998, 1996a, 1997
		Handique, R.	1996a, 1997
		Srivastava, V.K.	1996a, 1997
	Desert Medicine Research Centre (ICMR) New Pali Road, Post Box - 122	Bansal, S.K.	1995, 1996 a, b, c
	Jodhpur, Rajasthan	Singh, K.V.	1995, 1996 a, b, c

	(DMRC – JODHPUR)		
	Defence Research Laboratory P.O. Box No. - 2 Tezpur Assam -784001 (DRL – ASSAM)	Bhuyan, M. Das, N.G. Das, S.C. Baruah, I. Kamal, S. Talukdar, P.K. Santhonami K. Sarkar P.K.	1990, 1991, 2000 1997, 2000 1990, 1991, 1997, 2000 1990, 1991, 1997 1997 1991 1997 1997
	National Institute of Communicable Diseases Ministry of Health 22 - Sham Nath Marg Delhi - 110054 (NICD – DELHI)	Panda, R. Kumar, K. Gill, K. Katyal, R. Rahman, S.J.	1997 1996, 1997 1997 1997 1997
	National Institute of Virology (NIV) Pune, Maharashtra	Kulkarni, S.M. Geevarghese, G. George, R.J. Naik, P.S.	1991,1992 1992 1992 1991
	W.H.O. Short term consultant SEARO New Delhi	Kalra, N.L. Armarattana	1994,1997 1994

	Department of Zoology	Revana, M.A.	1993
	Univ. of Mysore,	Poornima	1993
	Karnataka	Pusplata, N.	1993
		Vijayan, V.A.	1993
		Vasudeva, K.S.	1993
	Department of Zoology	Pillai, M.K.K.	1991, 1992, 1996, 1991a
	University of Delhi,	Kumar, S.,	1991
	Delhi	Thomas, A.	1991
	Centre for Applied Genetics	Shetty, N.J.	1992
	Bangalore University, Bangalore	Bhasakar	1992
	Vector Control Research Centre (VCRC) Pondicherry, India	Jambulingam, P.	1990
		Sahu, S.S.	1990,1995
		Patra, K.P.	1995
		Gunasekaran, K.	1990
		Das, P.K.	1990
		Amalraj D.D.	1999
	Directorate of Health Services	Deobhankar	1990
	Pune, Maharashtra	Palkar	1990
	Department of Medical Entomology	Basak, B.	1995
	School of Tropical Medicine	Chakraborty, S.	2000, 1996, 1996, 1991
	Calcutta, West Bengal - 700073	Tandon, N.	2000, 1995
		Hati A.K.	1997
		Mukhopadhyay A.K.	1996, 1997, 1996, 1990, 1991, 1990

		Karmarkar P. Dey, P. Banerjee, P.	1996, 1997 1997 1996
	World Health House Indraprastha Estate, New Delhi	Kondrashin, A.V.	1992
Nepal	Epidemiology and Disease Control Division Department of Health Services Ministry of Health, His Majesty's Govt. of Nepal	Bista, M.B. Banerjee, M.K. Anonymous	1998, 2000 2000 1996, 1997, 1999, 2000, 2001
	Environmental Health Project HMG MOU USAID Program for the Prevention and Control of selected infectious Diseases in Kathmandu, Nepal	Anonymous	2000, 2001
	VBDRTC (Vector-borne Disease Research and Training Centre) P.O. Box - 12, Bhutan Devi Marg Hetauda, Nepal	Anonymous	1996, 1997, 1999, 2000, 2001