Role of Integrated Vector Management for Prevention and Control of Japanese Encephalitis/ Acute Encephalitis Syndrome (JE/ AES) - A Review

Roopa Kumari*, R. S. Sharma*, V. K. Raina**, L. S. Chauhan*

Abstract

In recent years, vector borne diseases (VBDs), have emerged as a serious public health problem. Repeated outbreaks of viral diseases, particularly Dengue fever, Chikungunya and Japanese Encephalitis (JE) are reported in the country. JE/AES is a main public health problem and is causing high mortality and disability. JE is a mosquito borne zoonotic viral disease and virus is maintained in animals, birds (Cattle egrets, pond herons etc.) and in pigs (amplifier hosts). JE is now an emerging viral disease having international importance because it is invading the previously non-endemic areas and major public health problem due to high case fatality rate and disability. JE/AES is currently reported from 25 states and Union Territories of India and repeated outbreaks are reported from eastern Uttar Pradesh, Bihar and Assam.

The risk factors, which play a key role in the spread and transmission of JE are, ecological changes due to developmental activities and climate change, expansion of agriculture, change of irrigation and crop pattern, constructions of irrigation and dams, poor environmental sanitation, migratory birds’ movement etc.. Vector ecology mostly determines the disease distribution. Factors that make the prevention and control of JE challenging are-outdoor habit of the vector, scattered distribution of cases spread over relatively large areas, role of different reservoir hosts making it difficult to control JE. Transovarial transmission is also known in the maintenance of JE virus. These are causes for much concern and highlight the need to comprehensively address the challenges faced in combating this disease in the country. There is a constraint to control JE due to its complex eco epidemiological ecology and entomological factors. Integrated vector management (IVM) is one of the key elements of vector control strategy and to reduce or interrupt transmission of disease. An IVM approach takes into account the available health infrastructure, resources and integrates all available and effective measures, whether chemical, biological, or environmental. This article provides an overview of IVM, along with all options available for prevention and control of JE.

Keywords: Japanese Encephalitis, Integrated Vector Management (IVM), India, vector control.

Introduction

Vector borne diseases (VBDs), such as malaria, dengue fever, Japanese Encephalitis (JE), yellow fever, and plague constitute a significant fraction of the global infectious disease burden. Indeed, nearly half of the world’s population is infected with at least one type of vector borne pathogen.1,2

*National Centre for Disease Control, 22 Sham Nath Marg, Delhi 110054
**National Vector Borne Diseases Control Programme, 22 Sham Nath Marg –Delhi 110054

Correspondence to: Dr. Roopa Kumari, National Centre for Disease Control, 22 Sham Nath Marg –Delhi 110054.
E-mail: dr_roopa@hotmail.com
In recent years, VBDs have emerged as a serious public health problem in the countries of the South-East Asia Region, including India. The maximum burden of VBDs in the South-East Asia Region is borne by India followed by Bangladesh, Sri Lanka, and Thailand. India is endemic for malaria, lymphatic filariasis, dengue, JE, and visceral leishmaniasis (kala-azar). The high burden of these diseases has a profound impact on the socioeconomic status and economic growth of the countries. 1,2 In addition to the adverse effect on the health of the people. Repeated outbreaks of viral diseases, particularly Dengue fever, Chikungunya and JE have been reported in the country. JE is now an emerging viral disease having international importance because it is invading the previously non-endemic areas, and is a major public health problem due to high case fatality rate and disability.

JE is a mosquito borne zoonotic viral disease. The virus is maintained in animals, birds, and pigs. Particularly, the birds belonging to family Ardeidae (eg. Cattle egrets, pond herons etc.), act as the natural hosts. Pigs are called the amplifier hosts in the transmission cycle, while men and horses are ‘dead end hosts’. The virus does not cause any disease among its natural hosts. Vector mosquito is able to transmit JE virus to a healthy person after biting an infected host with an incubation period ranging from 5 to 14 days. Transovarial transmission is also known to play a role in the maintenance of JE virus.

JE is the main cause of viral encephalitis in many countries of Asia with nearly 68,000 clinical cases every year. 24 countries in the WHO South-East Asia and Western Pacific regions have endemic JE transmission, exposing more than 3 billion people to risks of infection. 3 JE is now an emerging viral disease with international importance because it is invading the previously known non endemic areas. In India, the first human case was reported from Tamil Nadu, South India, in 1955. Before 1973, the disease seemed to have been limited to South India, until a severe outbreak occurred in districts of Bankura and Burdwan in West Bengal during 1973. In 1976, an outbreak was reported again in Burdwan district of West Bengal. Widespread occurrence of JE was recorded in the country during 1978. 4 Since then, JE/ AES has been reported in over 25 states/ Union Territories in India. 5 Still JE/ AES is a main public health problem and repeated outbreaks are reported in the country particularly from eastern Uttar Pradesh.

Ecological changes that are mainly caused by climate changes, expansion of agriculture along with change of irrigation and crop pattern, increase the transmission of vector-borne diseases particularly JE. 6 These are causes for much concern and highlight the need to comprehensively address the challenges faced in combating vector-borne diseases in the country. Control measures for vector borne diseases are important because most are zoonoses that are maintained in natural cycle involving animals and are not amenable to eradication; therefore, control measures generally focus on targeting the arthropod vector. For viral borne diseases such as dengue and JE, there is no specific treatment available hence, vector control is important.

Integrated vector management (IVM) is one of the key elements of vector control strategy to reduce or interrupt transmission of the disease. This article provides an overview of IVM, along with all options available for prevention and control of JE under Integrated Vector Management (IVM) mode.

**Integrated Vector Management (IVM)**

Integrated vector management (IVM) is one of the key elements of vector control strategy. IVM is a “rational decision-making process for the optimal use of resources in the management of vector populations, so as to reduce or interrupt transmission of vector-borne diseases”. IVM strategies use targeted interventions to remove or control vector breeding sites, disrupt vector life cycles and minimize vector–human contact, while minimizing the harmful effects of synthetic insecticides on the ecosystem. The approach seeks to improve the efficacy, cost-effectiveness, ecological soundness, and sustainability of disease-vector control. 1,4 Still in India, vector control measures are needed to be strengthened for all vector borne diseases including Japanese encephalitis under the mode of IVM.

A global strategic framework for IVM has been developed by WHO in 2004 and its objectives are to address the deficiencies in vector control and to improve the efficacy, cost-effectiveness, and ecological soundness. An IVM- based process should employ sustainable approaches compatible with local health systems. A regional framework for an IVM strategy for the SEA Region was developed in 2005 to advocate and help in implementing the IVM approach in the Member States. 5

The Global Strategic Framework for IVM identifies five key elements (figure 1) for the successful implementation of IVM. 10
An IVM approach takes into account the available health infrastructure and resources, and integrates all the available and effective measures, whether chemical, biological, or environmental. There is a need for continued research to identify and evaluate new tools for vector control that can be integrated with existing biomedical strategies within national control programmes.

This manuscript presents a report on the feasibility of operational IVM for combating vector-borne diseases in India particularly for JE control.

**Existing Vector control approaches in India**

Vector control is an important component in the prevention and control of VBDs, especially for transmission control. A national strategy for prevention and control of vector borne diseases is being implemented in the country by Directorate of National Vector Borne Diseases Programme (NVBDCP). Target sites for vector control for VBDs are larvae (immature) and adult. In rural & peri-urban areas, adult mosquito control by indoor spraying of residual insecticides is mainly used, while in urban areas, only larval control is promoted by using chemicals, biological control agents, bio-pesticides or by environmental management methods including source reduction.

**Implications of IVM in the Indian Context**

India is among the heartlands of vector-borne diseases in the world, characterized by enormous infrastructure, good human and financial resources, and a good health system. The presence of a multiplicity of vector-borne diseases in this situation presents a unique opportunity to explore the potential of a rational IVM strategy for multiple disease control and for optimizing limited resource utilization, while maximizing the benefits and providing a model for countries in a similar situation. There is a need to develop a national policy on the IVM strategy for prevention and control of these diseases.

Globally, IVM is predominantly being used for control of malaria. However, there is a need for continued research to identify and evaluate new tools for vector control of VBDs including Japanese Encephalitis that can be integrated with the existing control strategies.

**Prevention and Control of Japanese Encephalitis**

**JE Vectors**

_Culex vishnui_ subgroup mosquitoes, comprising _Cx. tritaeniorhynchus, Cx. vishnui_ and _Cx. pseudovishnui_, have been implicated as major vectors of JE in India as well as in many countries of south-east Asia. These mosquitoes are usually found in rural rice growing and pig-farming regions of Asia, but can also be found at the outskirts of cities in close proximity to human populations. They prefer to breed in rice fields,
and outbreaks of JE are commonly associated with intensive rice cultivation.\textsuperscript{14, 15}

JE virus has been recovered from 19 mosquito species in different parts of India and the prominent vectors are \textit{Culex tritaeniorhynchus}.\textsuperscript{17} Majority of the isolations were from \textit{Cx. tritaeniorhynchus} and this mosquito has been considered as the primary vector based on relative abundance, widespread distribution, and frequent virus infection. JE virus has also been isolated from \textit{Culex gelidus}, which prefers to breed in marshy depressions containing abundant aquatic vegetation. JE virus has also been isolated from Mansonioides species of mosquitoes. The aquatic plants such as \textit{Pistia}, \textit{Salvinia} and \textit{Eichhornia}, are essential for the larval development of Mansonia. In India, it was observed that Mansonia is probably a secondary vector which maintains JE virus during inter-epidemic period, with \textit{Cx. tritaeniorhynchus} as the primary vector. \textit{Cx. pseudovishnui}, \textit{Cx. whitmorei}, \textit{Cx. gelidus}, \textit{Cx. epidesmus}, \textit{Anopheles subpictus}, \textit{An. peditaeniatus} and \textit{Mansoniauniformis} are suspected to play some role in the epidemiology of JE in Gorakhpur.\textsuperscript{22} JE virus was also detected in adult mosquitoes raised from wild caught immatures and males of \textit{Cx. tritaeniorhynchus}, \textit{Cx. vishnui}, \textit{Cx. infusa}, \textit{Cx. gelidus}, \textit{Cx. fuscoccephala} and \textit{Ma. indiana}. Recently JE virus was detected from adult mosquitoes of \textit{Cx. tritaeniorhynchus}, \textit{Cx. gelidus}, \textit{Cx. pseudovishnui} and \textit{Cx. bitaeniorhynchus}, reared from wild caught immature from Gorakhpur region showing vertical transmission.\textsuperscript{8} Vertical transmission of JEV occurred in both hot and cool seasons. Thus the JE virus is regularly maintained in nature during the non-transmission seasons also.

Vectors of female mosquitoes get infected after feeding on a viraemic host. They can transmit the virus to other hosts after an extrinsic incubation period of 9 to 12 days. Some species of birds like pond herons, cattle egrets, poultry birds, ducks and sparrows, etc. appear to be involved in the natural transmission of JE virus. Migratory birds may be involved in the transfer of virus from one region to another. Cattle do not circulate virus in their blood but develop antibodies against them; hence they do not act as natural hosts for the virus. It is believed that the prevalence of an enormously large population of cattle in India as compared to pigs may act as a deterrent to the spread of JE infection, as the vector mosquito species have got more preference for cattle blood as compared to that of human beings. The pigs are thus considered to be “amplifier hosts” for the virus. They are capable of infecting a large number of vector mosquito species, which in turn may transmit the virus to man after the completion of extrinsic incubation period of 9-12 days. Humans become infected when they are bitten by infected mosquitoes, but since they have transient and low-level viraemia, they are “dead-end” hosts that do not normally transmit virus.

**JE Vector bionomics in relation to its Control**

JE vectors are mainly exophilic and endophagic in nature. The risk of transmission increases when the human dwellings and animal sheds particularly piggeries are situated very close to each other. When they are situated far from each other, the risk of transmission is reduced. Because of outdoor resting habits and crepuscular nature, the vector control using indoor residual spray is technically not feasible. In addition to this, due to vast and enormous breeding habitats like perennial ponds, paddy fields and other water bodies, larval control using various anti larval measures is also not feasible as it is resource intensive. Therefore, vector control using ULV (ultra low volume) fogging is the only recommended method of vector control and can be used during JE epidemics also.\textsuperscript{9}

A conducive ecosystem comprising of rivers, lakes, irrigation canals, ponds, reservoirs, and rice fields favour JE vector breeding. Surface water bodies such as ponds and canals are perennial breeding sources for JE vector breeding and provide a wintering and staging ground for a number of migratory waterfowls and a breeding ground for resident birds. They also act as mother foci for vector mosquitoes.\textsuperscript{3} After the monsoon, vectors spread to other water stagnation areas and rice fields. Thus breeding control with appropriate larvicides or using larvivorous fish in all permanent water bodies, before the start of monsoon and paddy irrigation, may check proliferation of breeding of JE vectors and may even contain the vector population during JE transmission season. The epidemic form of the disease and mortality due to JE can be minimized by applying the effective prevention or control measures in order to reduce the mortality.

**Environmental Factors**

Meteorological and anthropogenic risk factors can be used to forecast JE outbreaks, which in turn can help the health authorities to take appropriate measures to protect communities. The disease occurrence mostly coincides with the rainy season and the vector density. Comparison of rainfall data with JE incidence (figure 2) indicates vector density, and subsequently JE cases increase one month after the peak rainy months.\textsuperscript{8} During 2005
outbreak, the duration of rainfall was longer compared with other years, which explains the longest duration of JE outbreak in that year. Borah et al. 2013 also reported from Dibrugarh district of Northeast India that monthly minimum temperature and rainfall were significantly associated with JE transmission at one month lag. Regression analysis suggested that rainfall, minimum and maximum temperature, and relative humidity at 6:00 h are significant predictors of quarterly occurrence of JE cases. Additional anthropogenic risk factors including the conditions such as pig sty/cattle shed around and in lower part of the houses and proximity of rice field to the dwelling houses were also found to be predictors for JE occurrence.

Recent study indicates that Minimum Infection Rate (MIR) of both Cx. tritaeniorhynchus and Cx. gelidus mosquito species were positively correlated to percentage of JE positive cases and with rainfall, relative humidity, and negative relation with temperature. Rainfall, flood, humidity, and temperature are the important factors for transmission of JE. The eastern districts in Uttar Pradesh are the most prone to JE than western districts. Proneness of eastern districts of Uttar Pradesh to floods is attributed, among other things, to heavy rainfall, low and flat topography, and the silting of river beds, which make river levels to rise and have impact on temperature and humidity. As in Eastern UP, Bihar’s flood-prone area too tripled from 2.5 m ha in 1954 to 6.8 m ha in 1994. Flood proneness and water logging hit the lives and livelihoods of people in several ways including the growth of the vector mosquito population. Between 1951-1981, the area cultivated in kharif fell from 214 thousand ha to 68 thousand ha due to annual flooding and surface water logging; as a result, in these areas, farmers clung to traditional mixed-crop farming technologies. The tradition of animal husbandry too has been undergoing change due to waterlogging; as grazing lands remain submerged in water for long periods, large bovines have declined in population. Marginal farmers and landless have increasingly taken to piggery. All these factors contribute to increase of JE incidence in the eastern districts during the past decades. The most important long term strategy to counter flight flood-proneness is to rapidly increase groundwater irrigation which will not only lower water tables but also help reduce the intensity of floods which will further impact public health and improve the socioeconomic status of people in JE-affected areas. Awareness needs to be developed on personal protection against mosquito bites and the importance of early referral of cases.
Demographic variables and environmental factors play an important role in the spread of JE along with the population dynamics of the vector mosquitoes.

Existing Strategies for Prevention and Control of JE in India

Directorate of National Vector Borne Disease Control Programme is a nodal agency for control and prevention of Japanese Encephalitis/ Acute Encephalitis Syndrome (JE/AES) in the country. Approaches for prevention and control measures of JE/AES in India include: Effective Surveillance and monitoring system; Personal Protection, Fogging during outbreak, Health Education/Behaviour Change Communication (BCC) to promote early case reporting, segregation of amplifying hosts viz. pigs etc., Capacity building, Immunization and early diagnosis and proper management of JE cases to reduce case fatality.

Because of outdoor resting habits and crepuscular nature, the vector control using indoor residual spray is technically not feasible. In addition to this, due to vast and enormous breeding habitats like perennial ponds, paddy fields and other water bodies, larval control using various anti larval measures is also not feasible as it is resource intensive. Therefore, vector control using ULV (ultra low volume) fogging is the only recommended method of vector control and can be used during JE epidemics also.

However, a new initiative has been undertaken for prevention and control of JE/AES in India. Recently, Government of India has formulated a multipronged strategy to reduce morbidity, mortality, and disability in children due to JE/AES. This strategy will be implemented only with the active engagement of the Ministries/Departments of (i) Health and Family Welfare, (ii) Drinking Water and Sanitation, (iii) Social Justice and Empowerment, (iv) Women and Child Development, (v) Urban Development (Housing and Urban Poverty Alleviation), and (vi) Human Resource Development (Department of School Education and Literacy). Interventions will be focused during Phase-I of the programme in 60 districts in 5 states (Assam, Bihar, Tamil Nadu, Uttar Pradesh & West Bengal). Govt. of India has envisaged a multipronged strategy, encompassing preventive, case management and rehabilitation measures to address the problems relating to JE/AES. NVBDCP has developed draft guidelines for Prevention & Control of JE/AES. In a similar way, different sectors/divisions/ministry should also be included in planning & implementation of IVM activities for control of disease vectors.

Challenges for Prevention and Control of JE in India

Climate is the major driver include global climate change, including variation in rainfalls and environmental temperature. Migratory birds’ movement, pig rearing habits, changes in irrigation system, crop patterns, land use patterns, and constructions of irrigation and dams are the main factors contributing for distribution pattern of JE in India. Vector ecology mostly determines the disease distribution.

Factors that make the prevention and control of JE challenging are:

- Outdoor habit of the vector
- Scattered distribution of cases spread over relatively large areas
- Role of different reservoir hosts - water birds as reservoir and pigs as amplifying hosts
- Specific vectors for different geographical and ecological areas
- Immune status of various population groups is not known making it difficult to delineate vulnerable population groups.

Options for vector control intervention strategies for JE under IVM Mode

Vector control remains to be the most effective measure to prevent and interrupt the disease transmission and is therefore one of the basic technical elements of the vector-borne disease control programme. Control measures could be aimed at different stages of the mosquitoes in its life cycle. The measures can be classified as biological, environmental (physical), chemical control and personal protection interventions. Integrated mosquito management approach should be adopted for getting an effective and efficient control on mosquitoes with minimal impact on the ecological system. One or more measures could be selected from the biological, environmental, and chemical categories for controlling the target species. The effectiveness of the measures should be evaluated.

Following options (given on the next page) are mainly available/implemented for prevention and control of the JE vectors:
1. Environmental management control strategies

WHO defines Environmental Management for Vector Control as the planning, organising, carrying out and monitoring of activities for the modification and/or manipulation of environmental factors or their interaction with man with a view to prevent or minimise vector propagation and reducing man-vector-pathogen contact. Since Environmental Management was the mainstay of vector-borne disease control in the pre-DDT era, several historic reviews have highlighted the potential of this approach in the reduction of reliance on pesticides.

a) Alternate wet and dry irrigation (AWDI)

Rice fields have been known as the ideal breeding place for JE vectors and malaria vector mosquitoes (An culicifacies). Rice fields being the most productive breeding sites of Cx. tritaeniorhynchus, its population dynamics is closely associated with paddy cultivation. In Gorakhpur, a single paddy crop is grown per year and the majority of JE vectors show one peak a year, i.e. in September. The occurrence of JE in the region has therefore been closely associated with this peak. Interestingly, two peaks of JE vectors were recorded when double paddy crops were cultivated in Tamil Nadu. Control of JE vector breeding in rice field is a challenging task. Environmental management for vector control, such as alternative wetting and drying of rice fields can substantially reduce vector breeding while saving water, increasing rice yields, and reducing methane emission.

In China, large-scale application of the AWDI technique has been held responsible for significant reductions of rice field breeding JE vectors and malaria. A study found that AWDI has reduced the immature stages of Cx. tritaeniorhynchus by 14–91% in rice fields and adult population by 55–70%. The crop yield was examined in two trials, and increases between 4 and 13% were observed in AWDI rice fields.

In order to achieve a significant reduction of mosquito larvae, AWDI has to be applied during the entire cropping season and should cover all rice fields. This method is particularly feasible in places where control of water supply and drainage is possible, hence where soil and climatic conditions are suitable.

Limitations

The potential of AWDI is, however, limited in areas where there is a threat of insufficient resources to re-flood the fields and where farmers perceive a risk of reduced yields by letting their fields dry out. JE vectors are largely dispersed, thus intermittent irrigation should be applied to all rice fields over large areas, and during the entire cropping season, which is often not feasible.

b) Use of Neem-coated urea and water management

Rao et al. 1995 reported that use of neem-coated urea and water management by intermittent irrigation had a greater effect on grain yield and on control of breeding of culicine vectors of Japanese encephalitis, and also produced a slight but significant reduction in populations of anopheline. The neem fractions were relatively cost-effective, and the combined water management and neem-coated urea strategy is acceptable to farmers, who are already aware of the benefits of the use of neem-coated urea, and of water management. This technology is an environmentally friendly method of rice-field mosquito control that could sustainably be implemented by farmers.

Use of neem coated urea and water management system were found effective for the control of JE vectors in rice land eco system.

Limitation

Farmers are not aware of the effect of neem coated urea and there should be regular suppliers for that.

c) Segregation of pigs

JE vectors are exophilic and endophilic in nature. The risk of transmission increases when the human dwellings and animal sheds particularly piggeries are situated very close to each other. When they are situated far from each other, the risk of transmission is reduced. Since infected pigs act as amplifying hosts, domestic pig rearing is an important risk factor in the transmission of JE to humans. Pigs play an important role in the natural cycle and serve as an amplifier host since they
allow manifold virus multiplication without suffering from the disease and maintain prolonged viraemia. Thus, mosquitoes biting pigs can be dangerous for humans. In India, the state of UP contributed more than 75 percent of JE cases to the country. As per the last 17th livestock census, UP has the largest pig population in the country and unorganized piggeries are plenty here. Hence, the chance of human infection is high.

The removal of the pigs acting as amplification hosts appears to have stopped the circulation of JEV in Singapore. The incidence of reported serological confirmed cases of JEV has been declining since pig farming has been eliminated in the country. The incidence has dropped from 101 cases during 1977–1984 to 15 cases during 1985–1992.

**Limitations**

This intervention strategy may not be feasible in the resource-poor settings, where majority of the people consider pigs as a source of income and offood.

2. Biological control strategies

A wide range of organisms help to regulate mosquito populations naturally through predation, parasitism, and competition. Biological control methods for JE were also reviewed in 2011 from south east Asia. As biological control does not cause chemical pollution, it is considered to be a better method for mosquito control.

a) Larvivorous fish as a biological agent

The most commonly used predators are fishes. The essential features of a mosquito predatory fish are active top feeding and being carnivorous. Moreover, the efficient fish is small in size and is an insignificant source of food for humans. *Gambusia affinis* and *Poecilia reticulata* are generally extensively employed as biological agents for mosquitoes. After stocking rice fields with 1–10 natural predator fish perm, larval populations of *Cx. tritaeniorrhynchus* were reduced by 55.2–87.8%. However, these are just research observations and large scale field trials have not been successfully done for control of JE vectors.

**Limitation**

Larvivorous fish cannot be applied in rice fields, where irregular irrigation is practiced.

b) Bacteria as biocides

*Bacillus thuringiensis* (Bti) and *Bacillus sphaericus* (Bs) are naturally occurring bacteria. They have been used extensively as biological control agents against mosquito larvae. While Bti is effective on Anopheles larvae, Bs is more effective against Culex larvae. However, *Culex quinquefasciatus* has developed resistance to *Bacillus sphaericus* and other insecticides in the country.

In Tamil Nadu, India, the application of 4.3 kg/ha of a micro gel droplet formulation of *B. sphaericus* resulted in a 44–79% reduction of early instar and 82–100% reduction of late instar culicinae larvae (*Cx. fuscans, Cx. pseudovishnui* and *Cx. tritaeniorhynchus*) for at least 5 weeks. Similarly, up to 95–98% of *Cx. tritaeniorhynchus* larvae were reduced in three other field sites evaluating *B. sphaericus* or *B. thuringiensis* formulations. However, the larvicidal activity did not persist in these rice fields beyond a couple of days; in the Republic of Korea the residual effect of *B. Thuringiensis* H-14 was found to last only for 24 h.

**Limitations**

The application of larvicides may not be an appropriate control strategy in terms of cost effectiveness because of the widespread breeding reservoirs of *Cx. tritaeniorrhynchus*. Biocides are not only expensive but also their effectiveness can withstand only for a few days. Therefore, it requires frequent and repeated applications at least at the end of every week. In general, biocides are effective against mosquito larvae but cannot control the pupal stage.

c) Use of Azolla (Algae)

The floating water fern Azolla (Salviniales: Azollaceae) contains a symbiotic nitrogen-fixing cyanobacteria, *Anabaena azollae* Strasburger, and is regarded as a source of organic fertilizer for rice cultivation. Azolla multiplies rapidly and forms a thick surface mat, which has been shown, in laboratory studies, to interfere with oviposition of mosquitoes as well as adult emergence from pupae.

In China, the major vectors breeding in rice-fields say, *Cx. tritaeniorhynchus* and *An. sinensis* are found to have significant reductions of larvae in paddy fields where rice was cultivated in association with *Azollapinnata*. In Tamil Nadu, India, application of the floating water fern
Azollamicrophylla greatly reduced immature mosquito populations.

Limitation

However, the infestation of the rice field with Azolla was difficult to achieve and 80 percent coverage by Azollawas accomplished only 13–14 days after rice transplantation, limiting its wider use as a biological mosquito control agent.43

3. Chemical control strategies

Chemical control of vector populations with insecticides such as pyrethroids, organophosphates, and carbamates plays a marginal role in JE control. There are some advantages as well as limitations of various chemical control methods.

a) Indoor Residual Spraying (IRS)

As the main effect of IRS is the killing of mosquitoes entering houses and resting on sprayed surfaces, it is not useful for the control of vectors, which tend to rest outdoors, although it may be effective against outdoor biting mosquitoes, which enter houses for resting after feeding. IRS is relatively ineffective against the highly exophilic vectors, not only because of the resting habits of the vectors, but also because of the mobility of settlements, which remain unreported and inaccessible. In southern Henan province, China, DDT residual indoor spraying had no effect on the incidence of JE.44 The recent evidence shows that IRS is ineffective against JE vectors.45

However partial endophilic and endophagic population of JE vectors are recorded in India,19,46 therefore, behaviour change of vector mosquitoes should be considered to plan for vector control strategies in an area. Although mosquitoes of Culex vishnui subgroup preferred to rest outdoors, during the study period in 2011 in urban areas of Delhi,19 these mosquitoes were found both in indoor as well as outdoor resting habitats. Cx. vishnui collected from human dwellings was also found to be infection with JE virus; Cx. tritaeniorhynchus, the most incriminated vector of JE in India, was also reported resting indoors in large numbers during JE transmission season.46

Limitation:

Due to its exophilic and exophagic behaviour, the vector control using indoor residual spray is technically not feasible. However, vector bionomics may be considered for focal spray.

b) Other chemical control methods

Due to vast and enormous breeding habitats like perennial ponds, paddy fields and other water bodies, larval control using various anti larval measures is also not feasible as it is resource intensive. Therefore, vector control using ULV (ultra low volume) fogging is the only recommended method of vector control and can be used during JE epidemics (NVBDCP website). In some circumstances (for example, when an outbreak of JE occurs in a densely populated area), space spraying can break the transmission cycle for a short time.33 However, JE vectors tend to develop insecticide resistance. Usually this issue arises with insecticides that are not directly targeted to JE control, but are rather targeted to control other pests.

4. Personal protection interventions

a) Insecticide Treated Mosquito Nets (ITNs)

The insecticidal treatment of nets adds a chemical barrier to the often imperfect physical barrier provided by the net and thus, improves its effectiveness in personal protection.

The interventional strategy using ITNs will have an important epidemiological implication in bringing down the JEV activity in the pig rearing communities without disturbing their social custom of rearing pigs, which they have been carrying on for ages. As well, this may provide a cost-effective way to reduce JEV transmission and supplement the relatively high cost of vaccines.47 Use of ITNs will be effective particularly for elders, unvaccinated children, and outdoor sleeping community.

In southern Henan province, China, JE incidence was greatly reduced after the introduction of pyrethroid-impregnated bed nets. Only a small effect on outdoor biting densities of Culex tritaeniorhynchus was found, although the number of mosquitoes resting inside bed nets decreased markedly after the introduction of bed net impregnation.44

Limitations

Majority of the JE vectors have shown the bimodal feeding activity (the peak biting times after sunset and again after midnight) and people often stay outdoors at dusk hours, when ITNs may not be useful to reduce the man-vector contact. In addition, the JE vectors feed most often in the
outdoors and therefore, in these above circumstances deployment of ITNs may not be a feasible strategy. Hence, the application of repellents could be a useful alternative intervention measure. Since the biting activity of JE mosquitoes is at dusk, use of bed nets at night is likely to be ineffective and it shall not be the best solution for JE control.

b) Repellent

Repellents are playing a key role in order to reduce the man-vector contact and eventually to reduce the vector-borne diseases. Protection against insect bites is best achieved by avoiding infested habitats, wearing protective clothing, and applying insect repellent.

Insect repellents are extremely useful to the travellers, who visit the JE endemic areas for a short-span of time. The main advantage is that the repellents are relatively cheap, highly effective and can be applied as a short-term measure.

JE control in urban areas

JE risk was significantly associated with the rural residents living in close proximity to irrigated rice fields and pig-rearing places. However, in urban localities, JE cases were reported much closer to the ponds and ground water stagnation pools with vector breeding and pig-rearing localities. In Delhi, JE vectors were found to be breeding profusely in ponds and ground water collections in the parks. Therefore, in semi urban areas and in cities, such type of JE vector breeding sites should be targeted for vector control. High Cx. tritaeniorhynchus density was noticed as compared to rural areas in urban areas of Kurnool, India too.

Though JE is primarily a disease of rural agricultural areas, where vector mosquitoes proliferate in close association with pigs and other animal reservoirs, epidemics have also been reported in peri-urban and urban areas where similar conditions may exist. In such areas, JE vectors prefer to breed in small water bodies like ponds, ditches particularly in the presence of water hyacinth/aquatic plants (figure 3a). It was observed JE vector breeding in unused cemented irrigation canal with profuse aquatic vegetation in Bawana (NVBDCP). First time from urban areas of Delhi, indigenous transmission of JE has been reported, where vector, reservoir and amplifying host were found in the affected areas (figure 3). Vector mosquito of JE was found breeding in ponds and ditches. In Kerala, Mansonia breeds with aquatic plants. The weed provides numerous ideal day resting sites for Cx. tritaeniorhynchus and Cx. vishnui & Mansonia and the water underneath the plant is the ideal breeding ground for the mosquito. Fogging is ineffective at adult–resting sites—mechanical removal of water hyacinth is the best short term solution under IVM mode. Apart from health benefit, both biogas and fertilizer can be generated by utilization of water hyacinth after its removal from the water body. Sankar et al. developed a biogas-generation-vermi composting system for water hyacinth utilization. The system fully utilizes the weed in generating energy (in the form of biogas) and producing fertilizer in the form of vermicompost.
In urban areas, personal protection and biological control using larvivorous fishes and minor engineering method for source reduction may be the most preferable options for vector control. Therefore, Vector control/IVM requires coordinated efforts by Veterinary, Municipal/Urban Development Administration and Health authorities.

**Vector Control during Lean period**

During non-transmission period, breeding of JE vectors has been found restricted to limited breeding sites/mother foci, mostly in rural ponds. JE vector breeding was detected in small water bodies like ponds and ditches particularly in the presence of water hyacinth/aquatic plants (figure 3). Less effort will be required to control breeding in mother foci during the lean period. Biological control by using larvivorous fishes and even larvicides may be effective and feasible in limited breeding sites.

**Conclusion**

Vector surveillance should be strengthened during the lean period for mapping of vector breeding sites (mother foci) and for its control. Detection of...
early warning signals and taking effective and appropriate intervention measures will help to reduce child mortality due to JE. For predicting an outbreak, regular surveys of potential vector breeding sites, monitoring of vector density and detection of JE virus infection rates in vector mosquitoes will be required. \(^1\), \(^8\), \(^13\), \(^45\) Analysis of meteorological data such as rainfall, temperature and relative humidity also provides a reliable indication for JEV infection and occurrence of JE outbreaks. Apart from these, the other factors like agricultural practices, low socio-economic status, flood, virus amplifying hosts such as pigs, and its density and virus reservoirs might also play a major role in the disease transmission.

In summary, JE could be controlled with effective surveillance systems, segregation of pigs, and an integrated vector control approach under IVM mode. The concept of IVM was developed as a result of lessons learned from integrated pest management, which is used in the agricultural sector. In Sri Lanka, integrated pest and vector management in paddy cultivations have shown true benefits in controlling vector populations of JE and malaria. \(^13\) It needs to develop evidence based methods along with research/coordination with other sectors. Thus, there are a number of options for intervention strategies, available for IVM and therefore, one can select the appropriate intervention based on the local availability, accessibility, and affordability. Environmental management measures are most viable if they are readily integrated into a broader approach of pest management and vector management. \(^54\)

JE is mainly correlated with rice cultivation in rural areas. Trends of the rural population, the rice-irrigated area, and the rice production from 1963 to 2003 was analyzed, \(^26\) and it was reported that there was an increase of 22% in the rice harvested areas of all JE-endemic countries over the past 40 years. They also evaluated the effect of different vector control interventions in rice fields, including environmental measures (i.e. alternate wet and dry irrigation (AWDI)), and various biological control approaches. Further, it was suggested that in JE endemic rural settings, where vaccination rates are often low, an integrated vector management approach with AWDI and the use of larvivorous fish as its main components can reduce vector populations, and hence has the potential to reduce the transmission level and the burden of JE. \(^26\) Hence, intermittent irrigation system and use of bio-control agents and organic fertilizers (‘neem’ cakes) may be promoted, if possible. \(^45\) Rational use of appropriate insecticide in the resting sites of mosquitoes, viz; domestic and peri-domestic areas, cattle sheds, piggies, chicken coops etc. to suppress the vector density in risky areas should be done prior to transmission. \(^45\) Thus, there are a number of options for intervention strategies available for IVM and therefore, one can select the appropriate intervention based on the local availability, accessibility, and affordability.

**Way Forward**

- There is a need to show that IVM approaches are being implemented and that they are making an impact.
- Strengthening capacity-building for IVM at national, state, district level, particularly training of respective programme managers, decision-makers, and entomologists to improve the scope and implementation of IVM activities should be done.
- Selecting the community oriented, appropriate control strategy is extremely essential to minimize the mortality and morbidity due to JE. Currently, are a number of effective intervention strategies are available, from which the most appropriate intervention strategy can be selected depending on the local availability, accessibility, and affordability.
- There is need for a sustainable and legally recognized national IVM coordinating body with members drawn from different sectors. Interdisciplinary integration and inter-sectoral cooperation should be promoted by engaging appropriate stake-holders, including community groups and NGOs, and experts of vector-borne disease control. Further, coordinated national and local efforts and support are needed.
- Similarly, different sectors/divisions/ministry need to be included in planning & implementation of IVM activities for the prevention and control of VBDs including JE in the country.
- Japanese Encephalitis is mostly related to rice cultivation so vector management for breeding control with agriculture and irrigation system should be integrated as IVPM.
- To control vector breeding in mother foci during lean period, it is also important to reduce proliferation of vector density during transmission season.
JE is closely associated with the pattern of precipitation, flooding, and rice production systems. Analysis of trends and influencing factors should be done. It will help in designing suitable strategies for the prevention and control of JE in the country. Flood is found to be associated with JE, particularly in Uttar Pradesh, so planning is required for its management to control vector breeding.

Awareness should be created by effective health education campaign/BCC activities through print/electronic media viz., printed pamphlet, news papers, radio, and television. For personal protection, use of repellents, avoiding outdoor stay, wearing fullcover clothes at dusk hours during the transmission period, and segregation of pigs away from human population are needed.

Immunization of the vulnerable section of the society should be done.

In conclusion, JE could be controlled with proper planning and implementation of an effective integrated vector control approach under IVM mode and with the use of vaccine. Continuous monitoring of vector populations and JE virus infection rates in vector mosquitoes will help in predicting an outbreak, for which effective intervention measures should be taken.

Acknowledgement

We gratefully acknowledge the excellent technical support and guidance given by Dr Shiv Lal, Ex-Special DG and Director, NCDC and Consultant (JE), NVBDCP and Dr J P Narain, Senior Advisor (Epidemiology and EIS) for the preparation of the manuscript.

Conflict of Interest

All the authors declare to have no conflict of interest.

References


50. Sarkar A, Taraphdar D, Mukhopadhyay BB, Kumar M, Mukhopadhyay SK, Chatterjee S et al. Influence of socioeconomic status and environmental factors on serologically diagnosed Japanese encephalitis cases in the...


