

## Integrated vector management strategy in India: An overview of its scope and challenges innovative approaches to vector control

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### Abstract

Integrated Vector Management (IVM) is an affordable, effective, and efficient public health intervention for addressing the growing burden of vector-borne diseases, particularly in developing countries where resources are limited. Vector-borne diseases such as dengue and malaria, filaria and chikungunya continue to impose a heavy burden in terms of morbidity and mortality. In addition, they adversely affect the economy and act as a major barrier to socioeconomic development in developing countries like India.

Scope of Integrated Vector Management

- Reduction of the global and national burden of vector-borne diseases
- Elimination of malaria, lymphatic filariasis, and visceral leishmaniasis
- Improvement of public health and promotion of socioeconomic development
- Control of emerging and re-emerging vector-borne diseases
- Reduction of the financial burden caused by vector-borne diseases

### Pillars of Integrated Vector Management

- The following vector control strategies form the core components of IVM:
- Source reduction
- Appropriate larval control methods (Biological, Chemical and Genetical)
- Adult mosquito control measures
- Community education and participation in risk assessment and interventions
- Challenges in Implementation

Major challenges in the implementation of IVM include inadequate capacity building and poorly defined advocacy roles. The lack of a supportive legislative framework and insufficient intersectoral coordination further hinder effective implementation. Human resource development remains a significant challenge, as skilled manpower and adequate infrastructure from the central level to the grassroots level are essential prerequisites for successful IVM implementation.

Strengthening the implementation of integrated vector management strategies is crucial. Implementing agencies must analyze situational opportunities and ensure effective coordination. Active cooperation from all stakeholders is essential for achieving sustainable and successful outcomes.

**Keywords:** IVM, mosquito-borne diseases biological & chemical innovations, CRISPR, genomic strategies, Wolbachia

### Introduction

Integrated Vector Management (IVM) is defined as a rational decision-making process to optimize the use of all available resources for vector control. It promotes various interventions, alone or in combination, selected on the basis of local knowledge about the vectors, diseases and disease determinants. The IVM approach therefore facilitates tackling the area under influence of single or multiple vectors simultaneously (Beier, J.C *et al.*, 2008 <sup>[3]</sup>)

IVM is encouraged globally by World Health Organization (WHO) as it ensures benefits to community through judicious and evidence-based use of chemicals as vector control measures.

While promoting combination of novel tools, IVM also advocates elimination of Persistent Organic Pollutants (POPs) which have long run impact on environment. DDT is one of the POPs and it's phasing out for Indoor Residual Spray (IRS) under malaria programme and development of alternatives as per commitments.

IVM comprises following five key elements as depicted in Figure-1.

- Advocacy, social mobilization and legislation
- Collaboration within the health and non-health sectors
- Integrated approach to disease control
- Evidence-based decision-making
- Capacity building

### Material Methods

This work examines recent advancements in vector control methods with a focus on the integration of genomic, biological, environmental and chemical strategies as innovative approaches to address existing challenges. The methodologies discussed include genomic tools such as CRISPR/Cas9-mediated systems, biological interventions including *Wolbachia*-based strategies and sterile insect techniques (SIT), and chemical innovations involving insecticides with novel modes of action and advanced delivery systems (Alphey L. *et al.*, 2014 & Kyrou K, *et al.*, 2018) <sup>[2, 18]</sup>.



**Fig 1:** IVM comprises following five key elements as depicted

**Table 1:** Summary of Findings on Genetic Strategies, Biological Interventions, and Chemical Innovations in Vector Control

Field	Method	Key Finding	Challenges and Limitation	Future Opportunities
Genetic Strategies	Gene Drive Transcription	Reduced mosquitoes Population	Ethical and resistance	Development of reversible and localized gene
Biological Control	Wolbachia, Fungi and Fishes	Use of Wolbachia-infected mosquitoes significantly reduced the prevalence of diseases like dengue and Zika	Dependence on environmental condition	Combining Wolbachia with other methods
Chemical methods	New Insecticides	Development of insecticides with novel modes	Continuous application requirements and the risk of increased resistance	Combining novel insecticides with biological and genetic methods to reduce reliance on chemicals
IVM	Combining Strategies	Integration with gene, Biological and Chemical	Challenges in coordination and Implementation	Development of IVM mode

**Inclusion and exclusion criteria**

To maintain the quality and relevance of the selected studies, the following criteria were applied. Inclusion criteria required articles to be published in peer-reviewed journals, focus on genomic, biological, and chemical approaches to vector control, and include reviews, original research, or meta-analyses addressing innovative or integrated strategies. Papers highlighting field trials, laboratory studies, or computational models were also included. Exclusion criteria removed articles unrelated to vector control or focused on non-medical pests, studies with insufficient methodological details, and publications older than 1500 unless considered seminal works. The initial search identified 2420 articles, and after removing duplicates, 1852 articles remained (Jpt H *et al.*, 2008<sup>[17]</sup> and Liberati A *et al.*, 2009)<sup>[20]</sup>.

**Ethical considerations**

This review did not involve primary data collection or human/animal subjects. All included studies were assumed to have adhered to ethical guidelines, as summarized (Resnik DB *et al.*, 2019<sup>[29]</sup> and Lambert B. *et al.*, 2017)<sup>[19]</sup>

**Classification of strategies**

The identified vector control strategies were categorized into three main domains. These included gene editing techniques like CRISPR, gendrive system targeting vector reproduction and pathogen transmission, and transcriptomic and proteomic studies to inform target identification

(Genomic Approaches). Strategies included Wolbachia infected mosquito programs, the use of natural predators and parasites for vector suppression, and the integration of biological strategies with community-based interventions (Biological Approaches). These involved the development of insecticides with novel modes of action, the synergistic use of chemical compounds with biological agents, and innovations in delivery mechanisms such as microencapsulation and spatial repellents (Chemical Approaches) (Janes KA *et al.*, 2015 and Perveen N *et al.*, 2023)<sup>[16, 25]</sup>

**Result and Discussion**

The use of Wolbachia-infected mosquitoes has emerged as a ground breaking biological intervention. Wolbachia, a symbiotic bacterium, reduces the capacity of mosquitoes to transmit arboviruses, including dengue, Zika, and chikungunya. Large-scale field trials, such as, Wolbachia has been tested to enhance efficacy. These approaches have proven particularly effective in controlling isolated vector populations. Natural predators and parasites, including fish species such as Gambusia and fungal pathogens While these methods are environmentally friendly, their scalability and specificity remain limited compared to other interventions. The success of biological interventions is highly dependent on local ecological and social contexts. Community engagement and sustained funding are critical for the long-term implementation of such strategies (Alphey L *et al* 2010<sup>[1]</sup> and Huang Y-JS, *et al.*, 2017)<sup>[14]</sup>

### Elimination of Malaria, Filariasis and Visceral leishmaniasis

The vertical programs against Malaria, Filariasis etc. led to fragmentation of health systems by creating parallel systems for surveillance and planning, overburden on logistics and supply chain, depletion of scarce health care resources for achieving time bound targets of different programs by delivery of services like distribution of insecticide treated bed nets, mass chemotherapy etc. Therefore a single programmatic management including integrated delivery of health services by the designated health workers, involving holistic approach for vector control strategies and amalgamating all services will be more cost effective. (Chaitkin M *et al.*, 2019 & Rahi M *et al.*, 2021) [9, 28]

Vector control measures like indoor residual spray is beneficial for Malaria and Kala azar while use of larvicides is helpful for control of Malaria and Filariasis. Source reduction measures and improvement in environmental sanitation is an important strategy for control of breeding places of all vectors. Appropriate implementation of integrated vector management measures along with other strategies have potential to reduce the burden of three vector borne diseases that are targeted for elimination i.e. malaria, visceral leishmaniasis and lymphatic filariasis are targeted for elimination (visceral leishmaniasis and lymphatic filariasis by 2021 and malaria by 2030). To improve public health and Socioeconomic development Public Health is an important determinant of socioeconomic growth and development of a nation. Vector borne diseases like Malaria, Dengue etc are major threats to public health in India. Factors like deforestation, urbanization, construction projects, climate changes etc have significant impact on vector ecology and transmission of VBD (Berg H.V.D. *et al.*, 2021) [5].

Next-generation insecticide-treated nets

ITNs treated with a pyrethroid insecticide alone (effective for 20 washes and 3 years of use in the field) are currently referred to as LLINs (Ng'ang'a PN *et al.* 2021) [24]. The LLINs played a key role in reducing malaria by more than half a billion in Africa between 2000 [6] and 2015 (Bhatt S, *et al.*, 2000) [6]. Demonstration of advantage of PBO nets over synthetic pyrethroid nets and subsequent adoption of PBO nets by NCVBDC could pave the way for their application against resistant *An. culicifacies*.

### Integrated vector control methods

The IVM aims to improve the efficacy, cost-effectiveness, ecological soundness and sustainable disease-vector management. The strategies under IVM being advocated for major VBDs like malaria, dengue, chikungunya, Japanese encephalitis, lymphatic filariasis and visceral leishmaniasis have been elaborated (WHO 2017 & 2023), (Mariappan T *et al.*, 2014)

### Environmental modification

Environmental modification includes permanent or long-lasting physical transformation of land, water and vegetation to prevent, eliminate or reduce the breeding without causing undue adverse effects on the quality of human habitats. The examples are land leveling, alteration of drainage margins, flattening of breeding sites, maintenance of open ditches, free flow of water through proper gradient, etc.

### Environmental manipulation

Environmental manipulation consists of planned recurrent activity so that temporary breeding conditions are made unfavorable for breeding of vectors. Environmental manipulation activities include stream flushing, regulation of the water level in reservoirs, dewatering or flooding of swamps, clearing vegetation, etc.

### Changes to human habitation or behavior

- **Improved water supply:** Insufficient water supply during limited duration leading to water storage in various containers results in more breeding sites of mosquitoes. The proper supply of potable water will reduce storage practices and thus breeding as well.
- **Mosquito proofing of overhead tanks/ cisterns/ underground reservoirs/wells:** These structures should be properly covered with tight lids or using wire mesh to prevent mosquito breeding.
- **Mandatory water storage for firefighting:** Fire prevention regulations may require mandatory water storage; such storage tanks need to be kept mosquito-proofed. Similarly, petrol pumps, public entertainment & assembly, hospitals, hotels, underground shopping complexes, timber merchants having water tanks for firefighting should be properly covered to avoid any mosquito breeding inside them (Lindsay, S.W., *et al.* 2019) [21].
- **Solid waste disposal:** Solid waste like tins, bottles, buckets or any other waste material scattered around houses should be removed and treated as per solid waste management rules, 2016. Household and garden utensils (buckets, bowls and watering devices) should be turned upside down to prevent the accumulation of rain water, also plant waste e.g., coconut shells should be disposed of properly.
- **Tyre management:** Rain water accumulation in large number of improperly stored discarded tyres act as good breeding site for mosquitoes. To minimize the risk of mosquito breeding, tyres can be stored under a roof or covered to prevent the collection of rainwater; a hole can be made in tyres or filled with soil to avoid collection of water; and larvicides/ oil can be applied which kills larvae present in accumulated rainwater in tyres (.Bulletin de veille sanitaire [BVM] 2011).
- **Filling of cavities of fences:** Fences and fence posts made from hollow trees such as bamboo should be cut down to the node and concrete blocks should be filled with packed sand or concrete to eliminate potential Aedes larval habitats (Bibbs, C.S. *et al.*, 2017 Heydari, N., *et al.*, 2017) [7, 15].
- **Repellents:** Repellents are mainly used as topical application on exposed body parts for personal protection to prevent insect bites. They prevent human-insect contact for short duration and do not knockdown or kill. Therefore, these are useful for plantation workers, army people, labours, etc. who work outdoor and travelers (Salazar, F.V., *et al.*, 2012) [30].

## Chemical control

Chemical control measures are still considered as the most important component in the integrated control of vector borne diseases. These measures are recommended in permanent water containers where water has to be conserved or stored because of scarcity of water. Chemicals have been used to control vector borne diseases by attacking both larvae and adults of the vector species.

### A. Larvicides

Larvicides are used at an interval of week/fortnight to avoid emergence of adults because mosquito vector requires 7-14 days for its completion of life cycle depending on the temperature. Chemical larvicides are used in situations where disease vector surveillance indicates the existence of certain periods of high risk in localities where outbreaks might occur. Different larvicides which can be used (Chareonviriyaphap T *et al.*, 1999)<sup>[10]</sup>.

#### a. Temephos

Temephos is an organophosphorus compound with least mammalian toxicity. The chemical is being used as 50% emulsion concentrate (EC). It acts as contact poison which has a prolonged residual effect. One percent Temephos sand granules are applied to containers using a calibrated plastic spoon to administer a dosage of 1 ppm. This is recommended to apply in stored water like desert coolers, which are main source for *Aedes aegypti* breeding (Pinheiro VCS *et al.*, 2002 and Mohan L, *et al.*, 2008)<sup>[23, 26]</sup>.

#### b. Insect Growth Regulators

Insect Growth Regulators (IGRs) interfere with the development of the immature stages of the mosquito by interference of chitin synthesis during the moulting process of larvae or disruption of pupal and adult transformation processes (El-Aswad AF, *et al.*, 2007)<sup>[11]</sup>. Most IGRs have extremely low mammalian toxicity. Two compounds i.e., pyriproxyfen (0.5%) granular and diflubenzuron (25%) WP are recommended under programme (Gelman, D.B., *et al.*, 1995<sup>[12]</sup> & Hatakoshi, M., *et al.*, 1988)<sup>[13]</sup>.

## Conclusion

The implementation of Integrated Vector Management (IVM) strategies requires significant strengthening to achieve sustainable and effective outcomes. Implementing agencies must conduct systematic situational analyses to identify context-specific opportunities and constraints. Furthermore, effective implementation of IVM depends on coordinated efforts and active collaboration among all stakeholders, including governmental sectors, public health institutions, communities, and non-governmental organizations. This discussion highlights the transformative potential of integrating genomic, biological, and chemical strategies in vector control. Although significant challenges persist, the synergistic application of these approaches offers a promising pathway toward sustainable and effective management of vector-borne diseases. By addressing existing gaps and promoting interdisciplinary collaboration, the global public health community can achieve substantial reductions in disease burden and significantly improve public health outcomes worldwide.

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