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Review Article

Challenges and Opportunities for Integrated Vector Management in Developing Countries: A Narrative Review with a Focus on Iran

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Abstract
Background: Vector-borne diseases (VBDs), caused by pathogens transmitted through the bites of infected arthropod vectors, remain a major public health challenge in many developing countries. Environmental changes, urbanization, population mobility and health system limitations continue to sustain the transmission of these pathogens and the diseases they cause. Integrated Vector Management (IVM), recommended by the World Health Organization, provides a sustainable framework that combines evidence-based vector control interventions with surveillance, intersectoral collaboration, and community participation. However, implementation of IVM remains inconsistent, particularly in resource-limited settings.
Methods: This narrative review synthesized evidence from peer-reviewed literature indexed in PubMed, Scopus and Web of Science, supplemented by WHO technical guidance documents and regional surveillance reports published between 2000 and 2025. The review focused on IVM principles, implementation barriers, operational challenges and policy opportunities, with particular emphasis on Iran.
Results: The review identified several interconnected barriers limiting effective IVM implementation, including unstable financing, insufficient intersectoral coordination, gaps in entomological and epidemiological surveillance, limited community participation, inadequate technical capacity and increasing insecticide resistance. Evidence from Iran demonstrates substantial progress in malaria control while highlighting ongoing challenges related to leishmaniasis, emerging risks of *Aedes*-borne diseases, resistance management, and the need for stronger integration of environmental and surveillance systems.
Conclusion: Achieving sustainable reductions in VBD burden will depend on long-term commitment to integrated governance, resistance-informed decision-making and context-specific strategies that enable countries such as Iran and other developing settings to build resilient vector control systems.

Keywords: Descriptive review; Vector-borne pathogens; Vector control; Insecticide resistance; Surveillance systems

Introduction

Vector-borne diseases (VBDs) remain a major public health challenge in many developing countries, where climatic suitability, rapid urbanization, population mobility and health system constraints facilitate the transmission of malaria, dengue, leishmaniasis and other infections (1, 2). In response to the limitations of single-intervention and insecticide-centric approaches, the World Health Organization (WHO) has introduced Integrated Vector Management (IVM) as a

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rational, evidence-based decision-making framework that combines multiple vector control tools and emphasizes intersectoral collaboration and community participation (1). Integrated Vector Management forms a core component of the Global Vector Control Response (GVCR) 2017–2030, which calls for strengthened entomological surveillance, enhanced capacity and improved governance to achieve sustainable vector control and reduce disease burden (1, 2).

Despite significant progress in the early 2000s, recent global trends indicate persistent gaps and emerging threats. The World Malaria Report 2023 highlights ongoing high malaria burden and increasing financial shortfalls, compounded by climate variability, humanitarian emergencies and biological challenges that hinder elimination efforts in several regions (2). These developments reinforce the need for IVM as an adaptive framework integrating environmental management, biological control and judiciously targeted chemical interventions, guided by robust surveillance and routine monitoring (1, 2). A critical constraint is insecticide resistance (IR) in major vectors such as *Anopheles* and *Aedes*, which reduces the effectiveness of long-lasting insecticidal nets and indoor residual spraying. WHO provides standardized procedures for resistance monitoring and intervention selection, yet multi-class resistance continues to expand, emphasizing the need for diversified and context-specific toolkits within IVM (3–5).

In the WHO Eastern Mediterranean Region, progress has been uneven. Several countries achieved notable reductions in malaria transmission in the early 21st century, yet fragile settings, cross-border mobility and environmental change contribute to a persistent risk of resurgence (6). Iran serves as a clear example of both substantial progress and continuing challenges. The country has significantly reduced malaria transmission through strengthened surveillance and targeted vector control, while simultaneously facing ongoing burdens of leishmaniasis. Recent evidence indicates that visceral leishmaniasis remains endemic in defined foci with canine reservoirs, and cutaneous leishmaniasis continues to exhibit shifting spatial patterns driven by environmental and socioeconomic factors (7–9). These dynamics underscore the importance of integrated approaches that align vector control with reservoir management, environmental interventions and sustained community participation-fundamental principles of IVM (1).

Effective implementation of IVM in developing countries, and specifically in Iran, requires addressing governance and coordination gaps, securing predictable financing, strengthening entomological and analytical capacity, institutionalizing routine resistance surveillance, and embedding community engagement within program design and execution (1–4). Updated WHO guidelines for indoor residual spraying and insecticide rotation strategies offer adaptable frameworks suited to local ecological and health system conditions (3, 4, 10). This narrative review synthesizes the core components of IVM and examines key barriers to its implementation in developing settings, with emphasis on Iran, to inform practical policy and operational strategies aligned with GVCR objectives (1, 2).

Materials and Methods

This narrative review was conducted through a structured literature search performed in January 2025. Peer-reviewed articles published between January 2000 and January 2025 were identified from PubMed, Scopus and Web of Science databases. In addition, WHO technical guidance documents, global vector control reports and regional surveillance reports were reviewed to complement the published literature. The search strategy was developed using combinations of the following terms: "Integrated Vector Management", "IVM", "vector control", "malaria", "dengue", "leishmaniasis", "insecticide resistance", "entomological surveillance", "community participation" and "Iran". Boolean operators (AND/OR) were used to combine relevant search terms.

Studies were included if they addressed IVM principles, implementation strategies, evaluation of vector-borne disease control programs, operational barriers, policy opportunities, or epidemiological and entomological evidence relevant to developing country settings. Iran-specific studies and reports related to vector-borne diseases and vector control programs were also included. Studies focusing exclusively on clinical diagnosis or treatment without relevance to vector control, or those lacking sufficient operational or implementation-related information, were excluded. The literature selection process identified 76 articles for assessment. Following evaluation according to the predefined eligibility criteria, 57 articles were considered relevant and suitable for citation in the final narrative synthesis. Data were extracted according to predefined themes, including IVM components, implementation barriers, surveillance systems, insecticide resistance, financing and governance challenges, community participation, intersectoral collaboration and Iran-specific experiences. A narrative thematic synthesis approach was applied to organize and interpret the findings. Iran-specific literature was identified through targeted searches combining "Iran" with vector-borne disease-related terms, including malaria, leishmaniasis, dengue, insecticide resistance and vector control. Additional Iran-related evidence was obtained from national surveillance reports, Ministry of Health documents and WHO regional publications.

Results

Overview of vector-borne diseases in developing countries

Vector-borne diseases constitute a persistent share of the communicable disease burden in developing countries, where climatic suitability, rapid and unplanned urbanization, inadequate water and sanitation systems, population mobility, protracted crises and limited public health capacity collectively sustain transmission. Malaria, dengue, leishmaniasis, chikungunya, Zika and plague are among the most significant concerns, with overlapping ecological niches and seasonal patterns that complicate prevention and control. Evidence from program implementation demonstrates that single-tool, insecticide-centered strategies are insufficient in settings where vectors rapidly adapt and transmission foci are heterogeneous. Therefore, integrated approaches grounded in local eco-epidemiology, routine entomological surveillance and coordinated multi-sectoral action are required, as outlined in the WHO Global Vector Control Response 2017–2030 (1, 11).

Malaria remains the most closely monitored vector-borne disease in low- and middle-income countries. Despite substantial advances in the early 2000s, recent assessments indicate stagnation or reversal in several regions, driven by financing gaps, service disruptions, climate variability and biological threats (2). Sustaining coverage with long-lasting insecticidal nets and indoor residual spraying, improving diagnosis and treatment access and strengthening surveillance systems are essential but insufficient in the context of evolving vector behavior and resistance. Consequently, national programs are increasingly integrating complementary tools, stratified intervention packages and adaptive decision-making to address residual transmission (2).

Dengue has expanded significantly over the past decade, becoming hyperendemic in several tropical regions and spreading into subtropical and temperate areas. Record-high case numbers in the Region of the Americas and outbreaks in other regions underscore the role of climate anomalies, El Niño events and rapid urban growth in amplifying *Aedes*-borne disease risk (12, 13). The urban ecology of *Aedes aegypti*, characterized by artificial containers, intermittent water supply, solid-waste accumulation and close human-vector contact, necessitates community-centered source reduction, reliable water and sanitation services and con-

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sistent risk communication alongside targeted adult control during outbreaks (12, 13).

Leishmaniasis remains a major neglected tropical disease complex, with distinct clinical forms and vector species presenting operational challenges. Visceral leishmaniasis typically clusters in specific foci, often involving canine reservoirs, while cutaneous leishmaniasis exhibits shifting hotspots linked to land-use changes, peri-urban expansion and socio-environmental determinants (14–16). Effective control requires aligning vector control with reservoir management, early case detection and context-specific environmental measures, recognizing that transmission dynamics vary widely across and within countries (14, 15).

Cross-cutting drivers further intensify these challenges. Climate change is altering vector competence, survival and geographic distribution through shifts in temperature and precipitation patterns and increased extreme weather events (17–20). Rapid unplanned urbanization creates microhabitats favorable for container-breeding mosquitoes and burdens municipal services, while conflict and displacement disrupt surveillance and response capacity. Moreover, insecticide resistance, now documented across multiple insecticide classes in *Anopheles* and *Aedes* populations, threatens the effectiveness of core interventions and necessitates diversified toolkits, routine susceptibility monitoring and evidence-based rotation strategies (17–19).

Chikungunya demonstrates how rapidly arboviruses can emerge where competent vectors, immunologically naive populations and conducive climatic conditions coincide. Recent outbreaks across parts of Africa and Asia, along with sporadic transmission in temperate regions, highlight the need for integrated preparedness frameworks that combine entomological intelligence with risk communication, clinical readiness and, where applicable, targeted vaccination strategies (21–23).

In summary, the current landscape of vector-borne diseases in developing countries is shaped by ecological complexity, expanding arboviral threats, operational constraints and accelerating environmental change. Effective control requires Integrated Vector Management that is adaptive, data-driven and intersectoral, embedding community engagement, reliable essential services and rigorous resistance management within national strategies aligned with the WHO Global Vector Control Response (1, 17–19).

Concept and components of integrated vector management

Integrated Vector Management is a rational, evidence-based and locally tailored approach to vector control designed to optimize efficacy, cost-effectiveness, ecological safety and long-term sustainability. It incorporates multiple interventions targeting different stages of the vector life cycle, prioritizes data-driven decision-making and embeds community participation and intersectoral collaboration within national vector control strategies. The core principles of IVM include decision-making informed by entomological and epidemiological intelligence, selection of interventions based on local eco-epidemiological conditions, judicious use of public health pesticides, and continuous monitoring and evaluation to enable adaptive program management over time (Fig. 1)(1, 24). Within this framework, surveillance and monitoring guide the timing and geographic targeting of interventions; environmental management reduces breeding sites and structural risk factors; biological control expands available tools while decreasing reliance on chemical pesticides; chemical control is reserved as a carefully regulated last-resort option; and community participation and intersectoral collaboration ensure feasibility, local ownership and durable impact (1, 10, 24, 25). As summarized in Table 1, IVM consists of six core components that operate together within a data-driven and adaptive implementation framework.

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Surveillance and monitoring

Surveillance and monitoring constitute the decision-making foundation of Integrated Vector Management. Entomological surveillance provides information on vector species composition, density, behavior and spatiotemporal dynamics, whereas epidemiological surveillance characterizes disease incidence, prevalence and transmission foci. Programmatic monitoring evaluates the coverage, quality and effectiveness of implemented interventions. Collectively, these data support microstratification, enable timely outbreak responses and guide adaptive management in changing transmission settings (1, 24, 25). Standardized surveillance approaches include adult and larval sampling (such as modified traps for medically important flies (26), insecticide susceptibility testing and monitoring indicators such as parity rates, sporozoite rates and container indices for *Aedes* mosquitoes. The availability of routine, quality-assured datasets allows health authorities to identify residual transmission pockets, optimize combinations of interventions, and allocate resources where they yield the greatest marginal impact (10, 25). Where feasible, integrated digital platforms linking surveillance, logistics and case management systems can further accelerate decision-making processes and enhance operational accountability (1, 10, 25).

Environmental management

Environmental management aims to reduce human vector contact by preventing, modifying, or eliminating breeding and resting sites. In malaria-endemic areas, larval source management (LSM) is recommended as a supplementary strategy when aquatic habitats are "few, fixed and findable" and may include source reduction, environmental modification, and targeted larviciding with safe and approved agents. In urban environments dominated by *Aedes* vectors, sustained control depends on effective container management, reliable water provision, solid-waste collection and improvements in housing structure (27). Structural interventions such as installation of window and door screens, closure of eaves and enhancement of drainage help reduce indoor resting and breeding opportunities. Importantly, environmental management yields the greatest and most durable impact when integrated into municipal service systems, urban planning and routine community behaviors, rather than being conducted through temporary or reactive campaigns (1, 24, 28–30).

Biological control

Biological control broadens the IVM toolkit while reducing ecological disruption and slowing the development of insecticide resistance associated with repeated chemical use. WHO-prequalified larvicides such as *Bacillus thuringiensis israelensis* (Bti) and Spinosad provide targeted larvicidal activity with favorable safety profiles when applied according to recommended guidelines. For *Aedes*-borne diseases, population-replacement through the release of *Wolbachia*-infected *Ae. aegypti* has demonstrated significant reductions in dengue incidence and hospitalizations in randomized and quasi-experimental trials. Additionally, population-suppression approaches, including the Sterile Insect Technique (SIT), are increasingly being evaluated as components of integrated control strategies targeting *Ae. albopictus* and *Ae. aegypti*. The selection and deployment of biological control methods should be guided by local ecological characteristics, operational capacity, cost considerations and regulatory frameworks and should be supported by rigorous entomological and epidemiological monitoring to assess effectiveness and sustainability (25, 28, 31–33).

Chemical control

Chemical control remains an important but strictly last-resort component of IVM, applied primarily in situations requiring rapid vector reduction or during periods of high transmission when non-chemical interventions are insufficient. For malaria vectors, indoor residual spraying (IRS) represents the primary chemical

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control intervention, while insecticide-treated nets serve as a core preventive measure beyond the scope of this section. The selection of insecticide products, dosage, application quality and rotation strategies must be grounded in local susceptibility data and aligned with WHO recommendations to ensure effectiveness. Current guidance emphasizes the importance of resistance management through the rotation or mosaic use of insecticides with different modes of action, alongside strong operational safety measures, environmental protection and systematic quality assurance (34).

For *Aedes* vectors, targeted space spraying can be used to rapidly reduce adult mosquito populations during outbreaks; however, such interventions should be limited in duration, closely integrated with larval source reduction, and followed by post-intervention evaluation to confirm effectiveness. To sustain long-term impact, programs must institutionalize routine insecticide resistance monitoring and ensure that surveillance findings directly inform procurement decisions, intervention planning, and field implementation (3, 10, 25).

However, the increasing prevalence of insecticide resistance has important economic and operational consequences for vector control programs, particularly in low-resource settings. Resistance can increase program costs through the need for alternative insecticide products, expanded resistance surveillance, additional laboratory capacity, staff training and adjustments in intervention strategies. These financial demands may place additional pressure on vector control programs where funding mechanisms are already limited and often dependent on short-term or outbreak-driven allocations. The development of insecticide resistance in vector populations is not solely associated with public health insecticide use. Agricultural application of insecticides, particularly repeated exposure to similar chemical classes used in crop protection, may contribute to selection pressure among mosquito populations and other vectors. This interaction highlights the importance of intersectoral collaboration between public health, agricultural and environmental sectors to support comprehensive resistance management approaches within the framework of IVM. Although comprehensive resistance management strategies are recommended, their implementation in low-resource settings requires prioritization based on local feasibility and available resources. Practical approaches include targeted insecticide susceptibility monitoring, evidence-based selection and rotation of available insecticides, improvement of application practices, and integration of non-chemical interventions such as environmental management and biological control. Strengthening entomological capacity and ensuring that resistance data are incorporated into procurement decisions and operational planning are essential for preserving the effectiveness of available vector control tools.

Community participation

Community participation is essential for achieving sustainability and scalability within IVM programs. Successful initiatives foster local ownership by involving communities in the design and adaptation of interventions, promoting transparent risk communication, and encouraging shared responsibility for source reduction, housing improvements, and timely healthcare-seeking behaviors. Evidence from dengue and malaria control programs demonstrates that meaningful community engagement increases adherence to recommended practices, enhances environmental management outcomes and strengthens surveillance through participatory reporting. Sustained results depend on practical and context-appropriate tools such as household inspection checklists, behaviorally informed communication strategies, and integrated support from municipal services. Community engagement must be continuous rather than reactive, with activities anchored in routine public health practice and supported by well-trained community health workers and civil society organizations (1, 24, 35–37).

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Intersectoral collaboration

Intersectoral collaboration integrates the efforts of health, water and sanitation, waste management, urban planning, housing, education, environmental agencies and private-sector stakeholders to address the underlying determinants of vector proliferation. Municipal engineering interventions such as improved drainage systems, reliable piped water supply and efficient solid-waste management directly reduce breeding opportunities for *Aedes* mosquitoes. Housing and building standards can institutionalize vector-proof structural features, while environmental authorities can incorporate vector risk considerations into land-use planning. At the national level, formal coordination mechanisms are required to define sector-specific roles, financing pathways and shared monitoring indicators. Such institutional arrangements extend IVM implementation beyond the health sector, enhance program efficiency and embed vector control within routine governance and infrastructure development processes (1, 24, 38, 39).

Global status of integrated vector management

Integrated Vector Management has been incorporated into national vector control policies across many developing and middle-income countries following the introduction of the World Health Organization's Global Vector Control Response (GVCR) 2017–2030 (1). This strategic framework promotes evidence-based intervention selection, intersectoral collaboration, community engagement, strengthened entomological surveillance, and systematic resistance management (1, 24). Nevertheless, the extent and quality of IVM implementation vary widely due to disparities in financial resources, availability of trained personnel, and the robustness of data and surveillance systems (24).

Countries that have achieved sustained reductions in malaria transmission demonstrate some of the strongest operationalization of IVM principles. Sri Lanka and China successfully eliminated malaria by employing rigorous case detection and reporting systems, rapid response to focal transmission, and adaptive vector control strategies tailored to localized ecological conditions (10, 25). These national experiences highlight the critical importance of long-term governmental commitment, reliable surveillance structures, and integrated intervention packages rather than dependence on any single vector control tool (10, 25).

In many regions of Africa and Asia, IVM is reflected in malaria control program design, where the deployment of insecticide-treated nets and indoor residual spraying is increasingly informed by local insecticide resistance profiles (28). Larval source management is applied where breeding sites are few and accessible, and resistance monitoring capabilities are gradually expanding, although operational capacity constraints remain prominent in numerous settings (1, 28).

For *Aedes*-borne diseases such as dengue and chikungunya, several national and municipal programs have adopted IVM-based strategies that combine environmental sanitation, container and water-storage management, community mobilization and targeted adult mosquito control during outbreak periods (29). Notably, biological control interventions using *Wolbachia*-infected *Ae. aegypti* have demonstrated significant reductions in dengue incidence and related hospitalizations in real-world implementation studies (31).

Despite measurable progress, substantial challenges persist. Rapid informal urbanization, climate variability, cross-border disease movement and inconsistent or short-term funding mechanisms continue to limit the sustainability of IVM programs (1, 29). To enhance the long-term impact of IVM, countries require stable and predictable financing, improved municipal infrastructure and environmental services, expanded entomological and operational capacity and integrated digital surveillance systems that enable real-time decision-making (1, 24, 28).

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Barriers to integrated vector management in developing countries

Despite its demonstrated effectiveness and strong policy endorsement, the implementation of IVM in many developing countries is constrained by structural, operational and socio-environmental barriers. One of the most critical limitations is the lack of sustainable financing and stable resource allocation, which affects the continuity of surveillance activities, staff training, and procurement of vector control supplies (1). Funding for vector control is frequently reactive, increasing only during acute outbreaks, which disrupts long-term planning and compromises program stability (1, 4).

A second major challenge is the shortage of trained entomology and public health personnel. Effective IVM requires technical expertise in surveillance, insecticide resistance monitoring, ecological assessment and coordinated implementation of intervention packages (4). However, many national programs lack adequate numbers of skilled professionals, particularly at district and community levels, where operational activities are carried out (4, 25). Limited training opportunities and high workforce turnover further exacerbate these capacity gaps. Insecticide resistance (IR) presents an additional and increasingly significant barrier. Widespread resistance in *Anopheles* and *Aedes* vectors to multiple insecticide classes reduces the operational effectiveness of indoor residual spraying and space spraying interventions, including reduced efficacy of ITNs/LLINs after washing (34, 40–42). Without systematic resistance monitoring and evidence-based rotation strategies, chemical control becomes progressively less effective, potentially reinforcing transmission and increasing intervention costs (25, 40, 41).

In many developing countries, these technical constraints are compounded by weaknesses in the regulation and supply of public health pesticides. Fragmented registration processes, unclear mandates for quality control, and limited capacity for independent efficacy and safety evaluation permit the circulation of substandard or inappropriately formulated products alongside quality-assured insecticides. Informal or illegal importation and distribution channels further undermine regulatory oversight and make it difficult for national programs to enforce standards that are aligned with WHO guidance on rational insecticide use (1, 3, 24, 25). Such regulatory and market distortions not only jeopardize the safety and effectiveness of chemical control, but also complicate resistance management by enabling unsupervised household use and repeated application of the same active ingredients outside structured IVM programs.

Insufficient entomological and epidemiological surveillance systems also hinder effective IVM implementation. In many settings, surveillance remains fragmented, outdated, or limited to passive reporting. The absence of integrated data platforms delays outbreak detection and prevents the accurate targeting of control measures (25). Robust surveillance is essential to guide decisions regarding the use of larval, biological, or chemical control strategies (1).

Challenges in community participation further undermine IVM outcomes. Sustainable control of *Aedes* vectors, in particular, depends on consistent behavioral and environmental management at the household and neighborhood levels. However, public awareness, risk perception and willingness to adopt preventive practices are often low in densely populated areas with inconsistent municipal services (35, 43). Social, cultural and communication barriers can also limit community cooperation in eliminating breeding sites and participating in surveillance activities (35, 43, 44).

Finally, weak intersectoral coordination limits the capacity to address the environmental and infrastructural determinants of vector proliferation. Effective IVM requires coordinated

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action between health authorities, municipal services, water and sanitation departments, environmental agencies, and local governance institutions (1, 25). In many countries, such coordination mechanisms are either underdeveloped or insufficiently institutionalized, resulting in fragmented efforts or limited sustainability of interventions (1, 25, 44, 45).

Collectively, these barriers indicate that while IVM is conceptually well established, its successful implementation depends on long-term capacity building, stable financing, integrated data systems, community engagement and institutionalized intersectoral collaboration. A summary of these major implementation barriers is provided in Table 2.

Specific challenges and opportunities in Iran

Iran has achieved substantial reductions in malaria incidence over the past two decades; however, localized resurgence has been reported in southeastern regions since 2022, including two distinct malaria foci in Bushehr Province (46), driven by climate variability, cross-border population movement, and ecological suitability for *Anopheles* vectors (47, 48). In response, the World Health Organization (WHO) and the Ministry of Health and Medical Education (MOHME) have jointly strengthened surveillance, case management, and vector control operations in high-risk districts of Sistan and Baluchestan during 2024–2025, highlighting both the progress made and the vulnerability of border areas to reintroduction and sustained transmission (47). This recent resurgence should be interpreted as an indicator of the continued vulnerability of malaria elimination settings rather than simply a temporary increase in transmission. Despite substantial achievements in malaria control, the persistence of receptive ecological areas, cross-border population movement, and climate-related changes may facilitate reintroduction and localized transmission if surveillance and response capacities are not continuously maintained. This experience highlights the importance of sustaining IVM principles during low-transmission periods rather than relying primarily on outbreak-driven interventions.

Operational challenges to implementing IVM in Iran include episodic and outbreak-responsive financing, uneven entomological capacity across subnational levels, and logistical difficulties in maintaining high-quality indoor residual spraying and larval source management in remote and resource-limited settings (48). Insecticide resistance in *Anopheles* populations to multiple insecticide classes has been documented, threatening the durability of indoor residual spraying and reinforcing the need for routine susceptibility testing and rotation strategies consistent with WHO recommendations (49, 50). Strengthening laboratory networks, standardizing bioassay protocols, and ensuring that procurement and deployment decisions are informed by current resistance data remain core priorities (50). Beyond these operational constraints, regulatory and market-related weaknesses in public health pesticide management further complicate IVM implementation in Iran. Responsibilities for registering, procuring and supervising the use of public health insecticides are distributed across multiple institutions, including health authorities, agricultural agencies and municipal bodies, which can result in overlapping mandates and gaps in accountability. Limited capacity for independent quality control and efficacy testing facilitates the presence of non-standard or inadequately evaluated products in the market and constrains the ability of programs to enforce rational use consistent with WHO recommendations (1, 3, 24, 49). Illegal or informal importation and household-level access to potent insecticides outside professional supervision pose additional challenges for resistance management and environmental safety.

Challenges also arise from the organization of urban pest control services and vector management in institutional settings such as hospitals. In many cases, contracting for pest and vector control in health-care facilities and municipalities is driven primarily by administrative or procurement units, with limited technical

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oversight from medical entomologists or environmental health specialists. Routine residual spraying or space spraying may be prioritized to satisfy accreditation or inspection requirements, while structural and environmental measures that are central to IVM, such as improved waste management, building maintenance and exclusion of vectors from indoor spaces, receive insufficient attention (1, 10, 24). Licensing of private pest control companies does not consistently require demonstrated entomological expertise or robust quality assurance mechanisms, which can lead to suboptimal intervention design, unsafe application practices and further selection for insecticide resistance. These challenges reflect broader concerns within IVM implementation, where insufficient technical oversight and limited integration of medical entomology expertise may result in excessive reliance on chemical interventions rather than evidence-based, environmentally sustainable approaches. Strengthening regulatory frameworks, technical supervision, quality assurance mechanisms, and the involvement of trained vector control specialists are therefore essential for aligning private and institutional vector management practices with IVM principles.

Leishmaniasis presents additional and distinct challenges. Visceral leishmaniasis remains endemic in specific foci with established canine reservoirs, necessitating integrated strategies that align vector control, reservoir management and early case detection (7). Cutaneous leishmaniasis exhibits shifting hotspots and peri-urban expansion associated with land-use change, urban growth and socio-environmental factors, making single-intervention control strategies insufficient and underscoring the importance of municipal services, environmental management and sustained community engagement as central pillars of IVM (9, 51).

Recommendations and future directions

To translate IVM from policy formulation into sustained operational impact, recommendations should be prioritized according to urgency, feasibility and expected contribution to program sustainability. Although many implementation challenges are shared across developing countries, some priorities require context-specific adaptation based on national epidemiological profiles, health system capacity, and governance structures. Therefore, recommended actions can be organized into short-term, medium-term and long-term priorities, while distinguishing between broadly applicable strategies and specific needs identified in Iran.

Short-term priorities (0–2 years): strengthening core operational capacity

The immediate priority for developing countries should be to preserve the continuity and functionality of existing vector control programs by addressing critical operational gaps. Sustainable financing represents a fundamental prerequisite for effective IVM implementation. Ministries of health and finance should establish protected, multi-year budgetary allocations for vector control, link expenditures to measurable performance indicators, and integrate IVM activities into national health security frameworks to reduce dependence on outbreak-driven funding cycles (1, 2). Clear stewardship roles, standardized operating procedures and accountability mechanisms at national and subnational levels are essential to improve program stability and coordination (1). Strengthening surveillance systems should be considered another immediate priority. Countries should improve the integration of epidemiological, entomological, and operational data to support timely decision-making, intervention targeting and resource allocation. Routine entomological surveillance, insecticide susceptibility testing, and systematic analysis of residual transmission patterns should be strengthened through investment in medical entomology capacity and quality-assured laboratory networks (3, 25). Institutionalizing insecticide resistance management is also an urgent requirement. Routine susceptibility testing, evidence-based insecticide selection, rotation or

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mosaic strategies according to mode of action, and procurement decisions informed by current resistance data should become standard components of vector control programs (3, 10). Quality assurance, safe application practices, environmental safeguards and post-intervention evaluations should be mandatory elements of all chemical control operations, including indoor residual spraying (IRS) and targeted space spraying (10). For Iran, short-term priorities should particularly focus on maintaining malaria elimination achievements while addressing vulnerabilities associated with border transmission, ecological suitability and documented insecticide resistance. Strengthening sentinel resistance monitoring, improving laboratory networks and ensuring that vector control decisions are based on current susceptibility data remain critical priorities (48–50). In addition, improving technical oversight of public health pesticide procurement, quality assessment and distribution is necessary to reduce the risks associated with non-standard products and inappropriate pesticide use (1, 3, 24, 49).

Medium-term priorities (2–5 years): institutional strengthening and integrated management

Medium-term actions should focus on building institutional capacity and embedding IVM principles within routine health and environmental systems. Countries should establish integrated digital surveillance platforms that combine epidemiological, entomological, resistance and logistical information to support micro-stratification of risk and adaptive intervention planning (25, 55). These systems should be accompanied by standardized indicators, routine data review mechanisms, and strengthened analytical capacity at district and operational levels.

Workforce development is another essential medium-term priority. Countries should establish accredited medical entomology training pathways and provide continuous professional development for vector control personnel involved in surveillance, resistance monitoring, environmental management and intervention evaluation (3, 25). Medical entomologists and vector control specialists should be formally integrated into decision-making structures responsible for vector control policies, pesticide management, hospital standards and supervision of private pest control activities (1, 24, 25). Regulatory strengthening of public health pesticides should also be institutionalized during this period. Countries should clarify responsibilities for pesticide registration, procurement, quality control and post-market surveillance. National or regional quality-control laboratories, standardized lot-testing procedures and strengthened import inspection systems can reduce the circulation of substandard or falsified products and support rational insecticide use consistent with WHO recommendations (1, 3, 24). In Iran, medium-term priorities should include improving coordination among institutions responsible for public health pesticides, municipal pest control services and environmental health activities. The involvement of medical entomologists in hospital, municipal and private pest-control oversight should be strengthened to prevent excessive reliance on chemical interventions and to promote environmentally sustainable approaches. Licensing systems for private pest control companies should incorporate technical competency requirements, quality assurance mechanisms and adherence to IVM principles.

Long-term priorities (>5 years): sustainability, prevention-oriented systems and innovation

Long-term IVM implementation requires a transition from reactive vector control campaigns toward prevention-oriented systems integrated into routine governance structures. Environmental management should become a continuous service-based function rather than an intermittent outbreak response activity. Municipal authorities, water and sanitation services, housing sectors and health programs should collaborate to improve waste management, drainage systems, water supply reliability, housing standards and the reduction of vec-

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tor breeding and resting sites (1, 25, 56). Institutional environments, including hospitals, schools and public facilities, provide important opportunities to demonstrate sustainable IVM implementation. Rather than relying primarily on routine insecticide spraying for compliance purposes, facility-based vector management should prioritize structural improvements, environmental management plans, waste control, vector exclusion measures and involvement of trained vector control personnel (1, 10, 24). Scaling biological control and innovative approaches should also be considered within long-term strategies where ecological and operational conditions support their implementation. Larval source management using environmentally appropriate tools such as *B. thuringiensis israelensis* and *Spinosad* can complement other interventions when breeding habitats are identifiable and monitoring systems are available (56). For dengue prevention, *Wolbachia*-based approaches may be considered in settings with appropriate regulatory capacity, operational readiness and community support, accompanied by rigorous monitoring frameworks (32, 44). Novel tools, including next-generation insecticides, attractive targeted sugar baits and genetic approaches, should be evaluated under appropriate ethical, ecological and regulatory oversight (3, 10, 25, 57). Community participation should be considered a long-term strategic component of IVM rather than a short-term communication activity. Programs should use evidence-based behavior change approaches, develop locally adapted community microplans, engage community health workers and establish mechanisms for continuous evaluation of participation and environmental outcomes (1, 35). In addition, ministries of health, academic institutions and professional organizations should develop reliable information platforms to provide communities with evidence-based guidance on vector prevention, safe pesticide use and appropriate access to professional control services (1, 24, 35, 36). Finally, sustainable IVM requires formalized intersectoral governance mechanisms. National and subnational IVM coordination committees should include representatives from health, municipalities, water and sanitation, housing, education and environmental sectors, with shared targets, coordinated budgets where feasible, and harmonized monitoring frameworks (1, 25). Monitoring, evaluation, and learning systems should be embedded into program design, using indicators that capture entomological outcomes, disease trends, operational coverage, and cost-effectiveness. Periodic adaptive reviews and dissemination of implementation experiences can accelerate improvement and cross-country learning (1, 25, 55).

A prioritized implementation framework summarizing key actions, responsible actors, timelines and applicability to developing countries and Iran is presented in Table 4.

Table 1. Core components of integrated vector management and their roles

Component	Primary Objective	Example Interventions	Expected Outcomes
Surveillance and Monitoring	Enable data-driven decision-making and precise targeting	Adult and larval sampling, insecticide susceptibility testing, routine analysis of epidemiological trends	Optimized resource allocation, timely outbreak response, focused interventions
Environmental Management	Reduce breeding and resting sites and human–vector contact	Container management, drainage improvement, solid waste management, housing improvements	Sustained reduction in vector density, lower reliance on chemical control
Biological Control	Suppress vectors with minimal ecological impact and slower resistance selection	*Bacillus thuringiensis* israelensis, *Spinosad*, *Wolbachia* releases, Sterile Insect Technique	Durable impact, reduced chemical exposure, complementary control benefits

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Table 1. Continued ...

Chemical Control	Achieve rapid knockdown when risk is high and non-chemical options are insufficient	Indoor residual spraying, targeted space spraying, insecticide-treated materials	Immediate reduction in adult vectors, controlled outbreaks, requires resistance management
Community Participation	Sustain behavior change and improve local ownership	Co-designed microplans, household inspection checklists, risk communication, community health workers	Improved compliance, source reduction at household and neighborhood levels
Intersectoral Collaboration	Address upstream determinants through coordinated governance	Joint action by health, municipalities, water and sanitation, housing, education, environment	Integration of vector control into routine urban services and infrastructure cycles

Table 2. Key barriers to integrated vector management in developing countries and practical solutions

Barrier	Description	Practical Solutions
Unstable financing	Funding increases during outbreaks but declines afterward, disrupting long-term planning and operational continuity.	Establish multi-year dedicated IVM budget lines; integrate vector control funding into national health security plans; define annual operational targets and link budget allocation to measurable program indicators.
Limited technical capacity	Shortage of trained entomologists and vector control personnel, particularly at district and community levels.	Establish accredited medical entomology training programs; provide regular in-service training for provincial and district vector control staff; create and maintain dedicated entomology units within public health structures.
Regulatory and market distortions in public health pesticide management	Fragmented registration and quality control systems, circulation of non-standard or illegally imported public health pesticides, and weak technical oversight of procurement and distribution undermine safe and effective use of insecticides.	Define institutional responsibilities for pesticide registration and oversight; require pre-registration efficacy and safety assessments; strengthen national quality-control laboratories and import inspection systems; restrict distribution to licensed suppliers and ensure technical supervision of pesticide use.
Insecticide resistance	Reduced effectiveness of IRS and space spraying due to multi-class resistance in *Anopheles* and *Aedes* vectors.	Establish sentinel resistance monitoring sites; conduct standardized susceptibility testing at regular intervals; develop provincial resistance maps; use resistance data to guide insecticide selection, rotation, and procurement decisions.
Fragmented surveillance and data systems	Limited integration of entomological and epidemiological data delays outbreak detection and targeted response.	Develop integrated digital surveillance platforms linking disease cases, vector distribution, density, and resistance data; standardize reporting indicators; conduct routine data review meetings to guide microstratification and intervention planning.
Low community engagement	Limited awareness and participation in source reduction behaviors, especially in densely populated urban settings.	Develop locally adapted behavior-change communication programs; establish community-based vector surveillance activities; engage local leaders and community health workers; monitor participation using defined indicators.
Weak intersectoral coordination	Isolated sectoral actions fail to address environmental and infrastructural determinants of vector proliferation.	Establish national and subnational IVM coordination committees; assign clear responsibilities to participating sectors; develop joint operational plans and budgets; implement shared monitoring indicators for intersectoral activities.

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Table 3. Comparison of Integrated Vector Management status between Iran and selected countries

Country	Main VBD challenges	Key IVM components implemented	Main strengths	Remaining gaps
Iran	Malaria, leishmaniasis, emerging *Aedes* risks	Surveillance, IRS, vector control programs	Strong malaria reduction, established health network	Resistance monitoring, intersectoral coordination
Sri Lanka	Malaria elimination	Surveillance-driven response, integrated control	Successful elimination program	Maintaining prevention after elimination
India	Malaria, dengue, leishmaniasis	Integrated vector control, digital surveillance	Large-scale programs and surveillance networks	Regional heterogeneity
Pakistan	Malaria, dengue, leishmaniasis	IRS, LLINs, surveillance activities	Expanded vector control programs	Resource and coordination limitations
Turkey	Leishmaniasis, emerging arboviruses	Surveillance and environmental management	Strong health infrastructure	Need for integrated approaches

Table 4. Prioritized recommendations for integrated vector management implementation: timelines, responsible actors, and applicability

Timeline	Priority recommendation	Applicability	Responsible actors
Short-term (0–2 years)	Ensure sustainable financing, strengthen entomological surveillance, and establish routine insecticide resistance monitoring to support evidence-based vector control decisions	Generalizable to developing countries; highly relevant to Iran due to malaria vulnerability and documented resistance concerns	Ministries of Health and Finance; national and provincial vector control programs; entomology laboratories
Short-term (0–2 years)	Improve governance, regulation, and quality assurance of public health pesticides, including registration, procurement oversight, and product quality control	Generalizable; particularly relevant to Iran due to fragmented responsibilities and market-related challenges	Health regulatory authorities; pesticide control bodies; quality-control laboratories
Medium-term (2–5 years)	Develop integrated surveillance systems, strengthen medical entomology workforce capacity, and formalize IVM coordination mechanisms across health and non-health sectors	Generalizable to developing countries	Ministries of Health; universities; municipalities; water and sanitation and environmental sectors
Medium-term (2–5 years)	Strengthen technical oversight of institutional and private pest control services and integrate IVM principles into operational standards	Particularly relevant to Iran; applicable to settings with fragmented pest management services	Municipal authorities; hospital administrations; licensing and accreditation bodies
Long-term (>5 years)	Institutionalize environmental management, community engagement, and prevention-oriented vector control within routine health and urban systems	Generalizable	Health authorities; municipalities; community organizations; environmental agencies
Long-term (>5 years)	Evaluate and scale innovative and sustainable vector control approaches, including biological control and emerging technologies, supported by monitoring and adaptive learning	Generalizable but context-dependent	Research institutions; health authorities; regulatory agencies

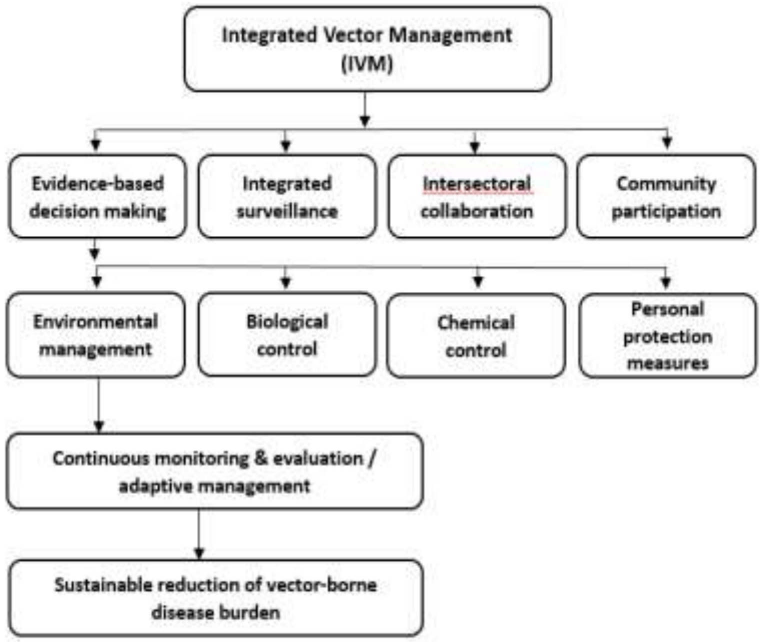

Fig. 1. Conceptual framework of Integrated Vector Management (IVM)

Discussion

Integrated vector management offers a practical, evidence-based framework for reducing the burden of vector-borne diseases in developing countries by aligning surveillance, environmental management, biological control, and carefully governed chemical interventions within an intersectoral structure (1, 25). Although IVM has been incorporated into policy in many settings, persistent constraints, including unstable financing, limited entomological capacity, fragmented data systems, widespread insecticide resistance and variable community participation, continue to limit its operational effectiveness (1–3, 25). Strengthening IVM will require institutionalized funding mechanisms, integrated surveillance systems that combine epidemiological and entomological data, routine insecticide resistance monitoring linked directly to product selection and deployment, and municipal service models that embed environmental management into daily operations rather than ad hoc campaigns (2, 3, 25). Evidence shows that locally tailored, multi-component intervention packages are more effective than reliance on any single tool. *Wolbachia*-based strategies have reduced dengue incidence when paired with container management and community engagement (32, 44), while resistance-guided indoor residual spraying and targeted larval source management can suppress residual malaria transmission where breeding habitats are few and accessible (2, 3, 25). Experience from multiple countries demonstrates that sustained progress depends on strong governance, rapid foci response and continuous program adaptation rather than dependence on a single intervention (1, 25).

In Iran, notable malaria control achievements, alongside evolving patterns of leishmaniasis and increasing suitability for *Aedes* establishment, highlight the need to consolidate IVM through cross-border vigilance, resistance-informed decision-making, and integration of environmental management with municipal and community systems (7, 47, 52–54). Looking forward, enduring reductions in vector-borne disease burden will rely on embedding adaptive management cycles, formalizing intersec-

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toral collaboration, expanding professional and operational workforce capacity, and investing in implementation research to refine context-appropriate strategies (1, 3, 25). Sustainable vector control will depend not on discovering a singular solution, but on effectively executing coherent, data-driven and resilient IVM systems capable of continuous learning and adjustment.

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Ethical approval

This review article did not involve any direct research on human or animal subjects. Ethical approval was not required as the study was based on analysis of previously published literature.

Conflict of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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