Management of insecticides for use in disease vector control: a global survey

Henk van den Berg  
Wageningen Universiteit

Haroldo Sergio da Silva Bezerra  
Organisation mondiale de la Sante

Emmanuel Chanda  
Organisation mondiale de la Sante

Samira Al-Eryani  
Organisation mondiale de la Sante

Bhupender Nath Nagpal  
Organisation mondiale de la Sante

Elkhan Gasimov  
Organisation mondiale de la Sante

Raman Velayudhan  
Organisation mondiale de la Sante

Rajpal Singh Yadav (✉ yadavraj@who.int)  
Organisation mondiale de la Sante  https://orcid.org/0000-0001-8264-1204

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Abstract

Background: Vector control plays a critical role in the prevention, control and elimination of vector-borne diseases, and interventions of vector control continue to depend largely on the action of chemical insecticides. A global survey was conducted on the management practices of vector control insecticides at country level to identify gaps to inform future strategies on pesticide management, seeking to improve efficacy of interventions and reduce the side effects of chemicals used on health and the environment.

Methods: A survey by questionnaire on the management practices of vector control insecticides was disseminated among all WHO Member States. Data were analysed using descriptive statistics.

Results: Responses were received from 94 countries, or a 48% response rate. Capacity for insecticide resistance monitoring was established in 68-80% of the countries in most regions, often with external support; however, this capacity was largely lacking from the European & Others Region. Procurement of vector control insecticides was in 50-75% of countries taking place by agencies other than the central-level procuring agency, over which the central authorities lacked control, for example, to select the product or assure product quality. Moreover, some countries experienced problems with estimating the correct amounts for procurement, especially for emergency purposes. Large fractions of countries across regions showed shortcomings in worker safety, pesticide storage practices, and pesticide waste disposal. Shortcomings were most pronounced in countries of the European & Others region, which has long been relatively free from mosquito-borne diseases but have recently faced challenges of re-emerging vector-borne diseases.

Conclusions: Critical shortcomings in the management of vector control insecticides are common in countries across regions, with risks of adverse pesticide effects on health and the environment. Advocacy and resource mobilization are needed at regional and country level to address these challenges.

Background

Human diseases transmitted by arthropod vectors account for approximately 17% of the estimated global burden of infectious diseases [1]. The most serious vector-borne diseases in terms of disease burden are malaria, dengue, lymphatic filariasis, onchocerciasis and leishmaniasis [2]. In many tropical and sub-tropical regions around the World, human populations are at risk from multiple vector-borne diseases [3]. The critical importance of vector control in managing these diseases has been emphasized [2, 4, 5]. For some diseases, such as dengue, zika and chikungunya, vector control and interruption of human-vector contact are the only available control options [6], for other diseases, like malaria, vector control has been playing a major role in control and elimination efforts [7].

The World Health Assembly recently adopted the Global Vector Control Response (GVCR) as strategy to strengthen capacity and coordination for vector control and public health entomology [1]. The GVCR is aligned with the key elements of the integrated vector management (IVM) approach, which seeks to make vector control more effective, efficient and sustainable, through evidence-based decision making, intersectoral collaboration, and an integrated approach to implementation [8, 9].

For the implementation of vector control, the GVCR calls for the use of efficacious interventions, with availability of high-quality vector control products, with capacity for optimal application, and minimizing the risks of pesticides to health and the environment. The mainstay methods for vector control depend largely on the action of chemical pesticides (specifically, insecticides), applied on substrates, on water surfaces, as spatial spray, or impregnated in netting materials. Hence, appropriate management practices are required throughout the pesticide lifecycle, including
on pesticide procurement, transport, storage, application and disposal [10]. Moreover, the routine monitoring and management of insecticide resistance is vital to preserve susceptibility to available vector control products in vector populations [11].

This paper describes the results of a global assessment on the management practices of vector control insecticides at country level. The objective is to identify gaps to inform future strategies on pesticide management, seeking to improve efficacy of vector control interventions and reduce the adverse effects of pesticides on health and the environment.

Methods

A questionnaire was prepared on the use and application of pesticides for vector-borne disease control, including procurement, insecticide resistance monitoring, quality control, safety precautions, storage, waste disposal and institutional aspects (see Additional File). Other components of the pesticide lifecycle, including manufacture, trade and regulatory control, are dealt with in a separate contribution [12]. The evaluation of operational procedures was not included in the questionnaire. Other public health pesticides, such as those directly applied on humans, household pest control products, and professional public health pest control products were not the focus of the questionnaire. The study was part of a comprehensive assessment of the global situation of agricultural pesticides and public health pesticides; the results of the comprehensive assessment have been documented in a different form as a separate report [13].

The questionnaire was translated from English into French and Spanish and disseminated through e-mail as editable Word® document from WHO’s headquarters via its regional and country offices to the national focal point in the Ministry of Health in each country. All 194 Member States of WHO were targeted for the survey. The questionnaire was distributed in December 2017. At country level, the national focal point was requested to have the questionnaire completed by the director of the main national vector-borne disease control programme (e.g. malaria, dengue), or (where applicable) by the national manager for vector control (i.e. person who has overall responsibility for entomological surveillance and vector control in the country). In countries with more than one national programme for vector-borne disease control, the malaria programme or vector control manager was requested to coordinate completion of the questionnaire.

For analysis of results, countries were grouped according to the United Nations Regional Groups of Member States, referred to as regions [14]. This classification differentiates the African, Asia-Pacific, Latin American & Caribbean, Eastern European, and Western European & Others Groups of countries. It is noted that the Western European & Others Group includes Australia, Canada, New Zealand, and the United States of America in addition to Western European countries. Because there were only four responses from the Eastern European Group, the data of the Eastern European Group were pooled together with those of the Western European & Others Group into the ‘European & Others Group’. Data were analysed using descriptive statistics. Questions with binary or numeric responses were selected for analysis. Questions with narrative responses, questions that appeared to be ambiguous in retrospect, and several questions that had been used in a more broad-based pesticide study [12] were excluded from the analysis.

Ethics approval and consent to participate were not applicable in this study.

Results
By December 2018, questionnaire responses had been received from 94 countries, indicating a response rate of 48% (Figure 1). The response rate was 54%, 55%, 76% and 19%, respectively, from the African, Asia-Pacific, Latin American & Caribbean, and European & Others regions.

Capacity for insecticide susceptibility testing (i.e. WHO or United States Centres for Disease Control and Prevention (CDC) phenotypic bioassays) was reportedly in place in most countries (68-80%) across regions (Table 1). An exception was the European & Others Region where the capacity for testing was less common (30% of responding countries), a result which is in line with the region’s low incidence of vector-borne diseases in recent history.

Representative sentinel sites, needed for monitoring of temporal changes in the prevalence of resistance, had been established in 36-57% of the countries in the Africa, Asia-Pacific and Latin American & Caribbean regions (Table 1). Insectaries to support insecticide susceptibility testing and efficacy testing were reported to be in place in 40-68% of countries across regions. Capacity for molecular testing and biochemical testing was reported from few countries but was most common in the African Region (36-39% of countries) (Table 1). Out of the 25 countries that reported the presence of molecular testing capacity, 20 also reported the presence of biochemical testing capacity. In total, 24 out of 25 countries with molecular testing and 23 out of 24 countries with biochemical testing also reported that capacity for susceptibility testing was in place. This suggests that molecular and biochemical testing were not used on their own, but together, and in combination with susceptibility testing. Furthermore, out of a total of 93 responding countries, 14 reported having all components (i.e. susceptibility testing, sentinel sites, insectaries, molecular and biochemical testing) in place.

### Table 1: Capacity for insecticide resistance monitoring

| Topic                             | African % (n) | Asia-Pacific % (n) | Latin American & Caribbean % (n) | European & Others % (n) |
|----------------------------------|---------------|--------------------|----------------------------------|--------------------------|
| Insecticide susceptibility testing | 68 (28)       | 70 (30)            | 80 (25)                          | 30 (10)                  |
| Representative sentinel sites established | 50 (28)       | 57 (30)            | 36 (25)                          | 10 (10)                  |
| Insectaries in place for bioassays | 57 (28)       | 50 (30)            | 68 (25)                          | 40 (10)                  |
| Molecular testing of resistance   | 39 (28)       | 17 (30)            | 28 (25)                          | 20 (10)                  |
| Biochemical testing of resistance  | 36 (28)       | 20 (30)            | 24 (25)                          | 20 (10)                  |

Data presented as % of responding countries per region that gave a positive response regarding each topic (n indicates number of responding countries for each topic)

Pesticide procurement is a demanding process to ensure the availability of correct amounts of quality products that are efficacious against targeted vectors. Some 80-92% of all countries in the Asia Pacific, African and Latin American & Caribbean regions claimed that insecticide susceptibility was factored into the procurement process (Table 2). Despite this, a smaller percentage (68-80%) had capacity for insecticide susceptibility testing in place (see Table 1). Out of a total of 75 countries that used insecticide susceptibility status as criterion in the procurement process, 17 countries did not have susceptibility testing capacity. This suggests that the procurement requirements could not be fulfilled everywhere, unless some countries sent entomological samples for testing abroad.

A small fraction of countries (8-27%) reported that problems were encountered with estimating the appropriate amounts of vector control insecticides to be procured for normal or routine situations (Table 2). However, a substantially larger fraction of countries (11-40%) experienced problems estimating the amounts needed for emergency situations (e.g. disease outbreaks), particularly in the African and Asia-Pacific regions.

In 73% of Asia-Pacific countries, a requirement for procurement of vector control insecticides was that quality control was conducted before and/or after shipment into the country (Table 2). This requirement was less common in the other regions (0-56% of countries), suggesting that in many countries the quality of procured consignments was not
guaranteed. Pesticide procurement may benefit from regional collaboration, for example, by combining the procurements of minor-use products between neighbouring countries to reduce costs. In this regard, 52% of countries in the Latin American & Caribbean Region reported that procedures, requirements and guidelines for procurement were aligned with those of other countries in the (sub-) region, whilst such alignment was less common in other regions (20-32%) (Table 2).

Table 2  Conditions and challenges of procurement of vector control insecticides

| Topic                                                                 | African | Asia-Pacific | Latin American & Caribbean | European & Others |
|-----------------------------------------------------------------------|---------|--------------|---------------------------|------------------|
| Insecticide susceptibility status as criterion for selection          | 89 (28) | 80 (30)      | 92 (25)                   | 38 (8)           |
| Problems estimating amounts needed for routine/normal situations      | 15 (27) | 27 (30)      | 8 (24)                    | 13 (8)           |
| Problems estimating amounts needed for emergency situations          | 32 (28) | 40 (30)      | 17 (24)                   | 11 (9)           |
| Quality control (pre- and/or post-shipment) required for procurement | 56 (27) | 73 (30)      | 36 (25)                   | 0 (9)            |
| Procurement requirements aligned with other countries                 | 22 (27) | 32 (28)      | 52 (25)                   | 20 (10)          |

Data presented as % of responding countries per region that gave a positive response regarding each topic (n indicates number of responding countries for each topic)

Most countries (63-84%), except in the European & Others Region, reported that the Ministry of Health procured pesticides for malaria control at central level (Table 3). Fewer countries in the African and Asia-Pacific regions reported central-level pesticide procurement for arboviral diseases (23-57%) and other vector-borne diseases (41-55%) (Table 3). The presence of central-level procurement does not mean that all vector control insecticides were procured that way. In 50-75% of countries there were other agencies or authorities apart from the central-level procuring agency, that procured pesticides for vector control (Table 3). These agencies or authorities, as reported by 69 countries, were local authorities, the private sector, donor-funded projects, and ministries other than Health (Table 4). In the African Region, the private sector and donor-funded projects (e.g. the U.S. President's Malaria Initiative) were the most commonly reported procuring agencies apart from the Ministry of Health. Local authorities were the most common procuring agencies besides the central Ministry of Health in the Asia-Pacific and Latin American & Caribbean regions, reported from 48% and 67% of countries, respectively (Table 4). In 22% of responses, procurement was centralized only; in 20% of responses, procurement was decentralized only; and in 58% of responses, procurement was both centralized and decentralized.

WHO routinely evaluates vector control products, and publishes recommendations on approved products [15]. In 81-87% of countries in the African and Asia-Pacific regions, procurement by the central-level Ministry of Health was restricted to those products that have been recommended by WHO (Table 3). However, products that were procured by other agencies at decentralized level were less commonly restricted to WHO recommendations in most regions (35-76% of countries) (Table 3).

Table 3  Procedures for procurement of vector control insecticides

| Topic                                                                 | African | Asia-Pacific | Latin American & Caribbean | European & Others |
|-----------------------------------------------------------------------|---------|--------------|---------------------------|------------------|
| Procurement for malaria control at central level                      | 63 (27) | 73 (30)      | 84 (25)                   | 20 (10)          |
| Procurement for arboviruses at central level                          | 23 (26) | 57 (30)      | 88 (25)                   | 11 (9)           |
| Procurement for other vector-borne diseases at central level          | 41 (27) | 55 (29)      | 77 (22)                   | 10 (10)          |
| Procurement by agencies other than at central level                   | 71 (28) | 72 (29)      | 75 (24)                   | 50 (10)          |
| Only WHO recommended products procured at central level              | 81 (27) | 87 (30)      | 68 (25)                   | 29 (7)           |
| Only WHO recommended products procured by other agencies             | 76 (21) | 50 (20)      | 35 (17)                   | 40 (5)           |

Data presented as % of responding countries per region that gave a positive response regarding each topic (n indicates number of responding countries for each topic)
Table 4  Agencies other than the national-level health ministry that procured vector control insecticides

| Agency                        | African (n=19) | Asia-Pacific (n=21) | Latin American & Caribbean (n=18) | European & Others (n=5) |
|-------------------------------|----------------|---------------------|-----------------------------------|-------------------------|
| Local authorities             | 26             | 48                  | 67                                | 80                      |
| Private sector                | 53             | 33                  | 22                                | 20                      |
| Donor-funded projects         | 37             | 10                  | 22                                | 0                       |
| Ministries other than Health  | 11             | 19                  | 17                                | 0                       |

Data presented as % of responding countries per region (n indicates number of responding countries per region)

Vector control spraying operations could adversely affect the health of spray workers, but health risks are reduced when adequate safety precautions are taken, for example, by using personal protective equipment. National guidelines or training curricula for safety precautions or risk reduction of spray workers for vector control operations were reportedly available in 70-71% of countries in the African, Asia-Pacific and Latin American & Caribbean regions (Table 5). However, national guidelines for health monitoring of spray workers in vector control operations (e.g. to detect signs and symptoms of pesticide poisoning) were present in only 11-44% of countries, depending on the region (Table 5), suggesting a major deficiency in health monitoring. Out of a total of 28 countries with guidelines on health monitoring, 26 also had guidelines on safety precautions in place. It remains unknown to what extent these guidelines were implemented, and who implemented them.

In countries where vector control operations were delegated or contracted to the private sector or to NGOs, these operations were monitored by the Ministry of Health in only 50-67% of the countries, suggesting that there were many delegated or contracted vector control operations that were not monitored by the health authorities (Table 5).

Furthermore, it was reported that those responsible for decision-making and implementation of vector control activities received certified training in vector control in only 25-44% of countries, which indicates a deficiency in capacity building (Table 5).

Pest control operators (PCOs) are private sector companies engaged in the control of domestic and peri-domestic pest problems, including insect pests. In 56-88% of countries across regions, PCOs were required to be licensed or certified (Table 5); licensing may or may not have involved specific training for PCO staff.

Table 5  Status of application of vector control insecticides

| Topic                                               | African % (n) | Asia-Pacific % (n) | Latin American & Caribbean % (n) | European & Others % (n) |
|-----------------------------------------------------|---------------|--------------------|---------------------------------|-------------------------|
| Guidelines for safety precautions of vector control spray workers | 71 (28)       | 70 (30)            | 71 (24)                         | 56 (9)                  |
| Guidelines for health monitoring of vector control spray workers | 29 (28)       | 27 (30)            | 44 (25)                         | 11 (9)                  |
| Delegated vector control operations adequately monitored | 67 (18)       | 54 (13)            | 56 (9)                          | 50 (6)                  |
| Vector control decision-makers trained in vector control | 44 (27)       | 38 (29)            | 36 (25)                         | 25 (8)                  |
| Pest control operators required to be licensed or certified | 65 (26)       | 63 (30)            | 56 (25)                         | 88 (8)                  |

Data presented as % of responding countries per region that gave a positive response regarding each topic (n indicates number of responding countries for each topic)

Vector control operations in which insecticides are used depend on a functional infrastructure for safe and secure transport and storage of insecticides and equipment. However, adequate, safe, and secure facilities for storing vector control insecticides at periphery level were available in only 24-67% of the countries and were least common in the...
Latin American & Caribbean Region (Table 6). Moreover, stock keepers at periphery level with adequate training on stock management were lacking from 33-50% of countries across regions (Table 6). In a 33-41% minority of countries across regions it was required that the transport of vector control insecticides to stores or points-of-use was accompanied by a person trained on safe transport and emergency procedures (Table 6).

At the end of spray operations, empty insecticide containers (e.g. tins, flasks, sachets) should be safely disposed, to avoid their reuse or refilling, and rinsate (mixture of pesticide with water resulting from cleaning of containers) should be reused [16]. However, 52-88% of countries across regions lacked a national guidance document on the safe and environmentally sound disposal of pesticide containers (Table 6).

Pesticides become obsolete after having expired, when their contents or packaging have deteriorated, when they are no longer needed for vector control, or when they have become de-registered or banned. Accumulation of obsolete vector control insecticides was reportedly a problem in 40-52% of countries in the African, Asia-Pacific and Latin American & Caribbean regions, but not in the European & Others Region (Table 6).

| Topic                                             | African | Asia-Pacific | Latin American & Caribbean | European & Others |
|---------------------------------------------------|---------|--------------|----------------------------|-------------------|
| Secure pesticide storage facilities at periphery level | 46 (28) | 55 (29)      | 24 (25)                    | 67 (9)            |
| Trained pesticide stock keepers at periphery level | 60 (25) | 50 (30)      | 65 (23)                    | 67 (9)            |
| Pesticide transport personnel trained on safety, emergency | 41 (27) | 37 (30)      | 40 (25)                    | 33 (9)            |
| Guidance on sound disposal of vector control pesticide containers | 46 (28) | 48 (29)      | 24 (25)                    | 22 (9)            |
| Accumulation of obsolete vector control insecticides not a problem | 56 (27) | 60 (30)      | 48 (25)                    | 100 (10)          |

At institutional level, a national vector control unit, with the responsibility for all vector control activities, was reportedly in place in 70-88% of countries across regions, except for the European & Others Region, where it was reported from only 30% of countries (Table 7).

The International Code of Conduct on Pesticide Management ('Code of Conduct') provides a framework for governments to manage pesticides throughout their lifecycle [10]. A 54-78% majority of countries reported that their Ministry of Health used, or referred to, the Code of Conduct in the management of public health pesticides. An exception was the European & Others Region where the Code of Conduct had reportedly not been used for public health pesticides in 8 out of 9 countries (Table 7).

In 18-56% of countries, the central-level Ministry of Health did not have available records on the use of vector control insecticides, suggesting that the authorities may not keep track of the amounts and types of insecticides used in the country (Table 7).

| Topic                                           | African | Asia-Pacific | Latin American & Caribbean | European & Others |
|-------------------------------------------------|---------|--------------|----------------------------|-------------------|
| National vector control unit in place           | 82 (28) | 70 (30)      | 88 (25)                    | 30 (10)           |
| Use of Code of Conduct for public health pesticides | 78 (27) | 69 (29)      | 54 (24)                    | 11 (9)            |
| Records available on use of vector control insecticides | 71 (28) | 82 (28)      | 80 (25)                    | 44 (9)            |

Data presented as % of responding countries per region that gave a positive response regarding each topic (n indicates number of responding countries for each topic)
Discussion

The vectors of major human diseases are developing resistance to available insecticides [17-20]. Capacities needed for routine monitoring of insecticide resistance have been established in part of the countries in regions with high burden of vector-borne diseases, as indicated in this study. Recent capacity building efforts, in terms of a number of regional and national training courses on insecticide resistance monitoring, have likely contributed to this result [21, 22]. The standardized insecticide susceptibility tests, which measure phenotypic resistance, are the most common monitoring tools and can be implemented at a relatively low cost, but also have their limitations in terms of fluctuations in results and monitoring the intensity of resistance [5, 23-25]. Biochemical and molecular techniques are instrumental for identifying the mechanism of resistance and for detecting low frequencies of resistance genes in vector populations; however, these techniques depend on sophisticated equipment. Capacity for biochemical and molecular testing was most common in the African region, most likely in connection with recent investments into the region by malaria control and elimination programmes [26]. Availability of these techniques for dengue vectors was probably more limited.

Despite these positive findings about capacities for monitoring of insecticide resistance, many countries are apparently still lacking the basic capacities for management of insecticide resistance. Even though it is imperative that countries generate insecticide susceptibility data for targeted insect vectors to inform their decisions on vector control products and interventions, it is a challenge in many countries to utilize these monitoring data for optimal decision making [21]. In addition, alternative options of insecticides with different modes of action may not be registered or available at country level. Apart from insecticide susceptibility, the effectiveness of interventions is also an important consideration in decision making, bearing in mind that evidence on the effectiveness of vector control methods is scarce for dengue but substantial for malaria [27, 28].

Another important finding is that, even though most countries have a system of centralized procurement of insecticides for vector-borne disease programmes in place, in many countries procurement is also taking place by other agencies including decentralized authorities. Unlike malaria programmes, dengue programmes in Asia and Latin America commonly have a decentralized organizational structure characterized by a shortage of technical expertise [29]. Centralized procurement of pesticides, as for medical supplies, has advantages over decentralized procurement in terms of efficiency, control over product selection, negotiation on price and quality, quality control, and prevention of accumulation of expired stocks. A special concern is our finding that that decentralized procurements in responding countries gave less consideration to WHO-recommended products as compared to centralized procurements. Moreover, decentralized procurements are less likely to incorporate costly quality control, especially considering that quality control was generally weak across regions. Consequently, in many countries, procurements of vector control insecticides are taking place over which the central authorities apparently have no or little control.

A related issue is that a considerable number of countries expressed difficulties in estimating the amounts needed to be procured, especially for emergency situations. Under-estimation could have serious implications for outbreak control. Over-estimation could contribute to the accumulation of obsolete pesticides; the environmentally sound disposal of obsolete pesticides is known to be very costly [30]. For countries expressing these difficulties, guidance or training tailored to their specific needs would be helpful.

Aspects of worker safety, pesticide storage practices, and pesticide waste disposal were a common weakness in vector control programmes across regions that can result in external costs of pesticides to health and the environment. This suggests that budgetary decisions by government agencies or donors have commonly emphasized the operations to achieve coverage of vector control, while financial and logistic support for health and environmental
safety measures of those operations were often neglected. For example, independent observations in selected countries suggest that countries which opted for space spraying operations to control dengue fever in many cases did not have the available resources allocated to support health checks of spray teams, to provide insurance or compensation in case of pesticide poisoning, or even to provide the basic personal protective equipment [31]. This calls for critical review at country level. To guide policy reform, coordinated investigation into the prevalence of signs and symptoms of pesticide poisoning among vector control spray workers is needed, including on space spraying, a method which relies on airborne insecticide formulations.

The European & Others Region has scored rather poorly in the survey, particularly in relation to the capacity for insecticide resistance monitoring, availability of guidelines, and vector control training. Most countries in this region have long been relatively free from mosquito-borne diseases, apart from introduced disease cases, and endemic leishmaniasis in the Mediterranean and Central Asia [32]. However, recent outbreaks of (re-) emerging vector-borne diseases like dengue, chikungunya and West Nile virus, together with the spread of invasive vectors, notably *Aedes albopictus* and *Ae. aegypti*, highlight the importance for countries in this region to establish adequate capacity to tackle these challenges [33-35].

A limitation of the study was that the focal points to which the questionnaires were addressed may not have had access to information regarding all questions. Moreover, the 48% response rate suggests that the data provided a moderate representation of the global situation. Language barriers, for example, with Russian-speaking countries, or unavailability of the solicited data at the national level may have curbed the response rate. Another limitation of the global questionnaire was that questions and responses lacked depth and, thus, raised additional questions. To provide more insight into the situation of vector control insecticide management, a separate study in six selected countries addressed the causes of deficiencies, the context in which decisions have been made, and the opportunities for structural improvements [31].

Special efforts on advocacy and resource mobilization are necessary to assist countries in addressing their critical shortcomings in the management of vector control insecticides. At regional level, support could be provided for regional policy development, thematic technical support across countries, and in-depth analysis and planning in selected countries [36]. At country level, vector control programmes in which insecticides are used should make adequate budgetary allocation to insecticide resistance monitoring, pesticide procurement methods, worker safety, pesticide storage, and pesticide waste disposal.

**Conclusions**

Vector control interventions continue to depend largely on the action of chemical insecticides. Results from the global assessment indicated how insecticides are managed in the practice of vector control. Capacity for insecticide resistance monitoring has been established in part of the countries, often with external support; however, this capacity is still lacking from other countries. The procurement of vector control insecticides is often taking place at decentralized levels, over which the central authorities lack control, for example, on product selection or quality control. Moreover, some countries experience problems with estimating the correct amounts for procurement, especially for emergency purposes. Countries across regions showed critical shortcomings in worker safety, pesticide storage practices, and pesticide waste disposal. These shortcomings call for increased attention to pesticide management in international support, budget allocation and regional collaboration (Table 8).

Table 8. Recommendations to countries and funding agencies, as appropriate
Recommendation

1. Invest in capacity building for monitoring and management of insecticide resistance
2. Establish centralized procedure for the procurement of vector control insecticides, with provisions for pesticide quality control
3. Establish procedures and mechanisms to protect and monitor the health of vector control spray workers
4. Improve pesticide storage practices, stock management, and sound disposal of obsolete pesticides and waste

Abbreviations

CDC: United States Centres for Disease Control and Prevention; GVRC: Global vector control response; IVM: Integrated vector management; NGO: Non-governmental organization; PCO: Pest control operator; WHO: World Health Organization.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

The country-anonymized dataset is available from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

RY, RV and HvdB conceived the study. HvdB and RY designed the questionnaire. SAE, EC, EG, BNN, and HSB supervised the data collection. HvdB analysed the data and drafted the manuscript. All authors read and approved the final manuscript.
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