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Managing insecticide resistance in malaria vectors in Africa: case studies from Cameroon, Côte d'Ivoire and Tanzania

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Abstract

Background Malaria remains a significant public health challenge in sub-Saharan Africa (SSA), where vector control strategies, particularly insecticide-treated nets (ITNs) and indoor residual spraying (IRS), have played a critical role in reducing transmission. However, the emergence and spread of insecticide resistance among malaria vectors threatens to undermine these gains. In response, many countries in the region have developed national insecticide resistance management (IRM) plans. This study evaluates the adequacy and implementation of these plans in Cameroon, Côte d'Ivoire, and mainland Tanzania, aiming to identify key challenges and best practices, and to develop actionable recommendations applicable to these and other countries with similar contexts.

Methods A mixed-methods approach was employed, incorporating document reviews, epidemiological and entomological data analysis, and discussions with stakeholders and experts in 2023. The evaluation focused on the alignment of national IRM plans with national malaria control strategies, their operational effectiveness, and the ability to guide effective monitoring and management of insecticide resistance. The assessment was conducted before changes in the global aid funding landscape.

Results Each country has developed a 5-year IRM plan; however, the plans for Côte d'Ivoire and mainland Tanzania were found to be outdated. While the plans align well with national malaria strategies and international guidelines, implementation has been hindered by inadequate domestic funding and heavy reliance on external donors. Sentinel site coverage for resistance monitoring remains limited, though ITN campaigns have increasingly adopted targeted approaches using varied net types based on local data. IRS is sparsely deployed, but where it is used, rotation of insecticides with differing modes of action is practiced. Despite existing strengths, such as subnational tailoring of interventions, major challenges persist, including inactive monitoring sites and limited data availability due to financial and logistical constraints. The assessment identified important recommended actions, including increased mobilization of domestic financing of resistance monitoring and management to offset shortfalls in external funding, updating of national IRM plans regularly by realistically aligning with available resources, and improved tailoring of effective vector control through high-quality and localized resistance and malaria risk data.

Conclusion Insecticide resistance remains a significant threat to malaria control efforts across sub-Saharan Africa. Robust, adaptable IRM plans are essential to address this challenge. Case studies from Cameroon, Côte d'Ivoire,

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and mainland Tanzania reveal that such policy plans exist but implementation gaps, largely driven by funding short-ages (a challenge that has increased since the study was completed), undermine the effectiveness of existing strate-gies. Strengthening domestic resource mobilization, enhancing multisectoral coordination, and investing in system-atic entomological surveillance are critical to ensure evidence-based, sustainable vector control programmes.

Keywords Insecticide resistance, Malaria, Resistance management, Cameroon, Côte d'Ivoire, Mainland Tanzania

Background

Malaria remains a significant global health challenge, particularly in sub-Saharan Africa (SSA). In 2023 alone, an estimated 263 million cases and 597,000 malaria-related deaths were recorded worldwide, with 95% of the deaths occurring in the World Health Organization (WHO) African Region [1]. Vector control strategies, especially indoor residual spraying (IRS) and insecticide-treated nets (ITNs), have played a crucial role in reducing the disease burden. Between 2000 and 2015, these inter-ventions are estimated to have prevented 663 million clinical malaria cases across SSA [2]. However, progress has begun to plateau, with growing insecticide resistance emerging as a major threat [3], particularly given that most vector control measures rely heavily on insecticide use [4].

WHO defines insecticide resistance as the heritable ability of a strain of insects to survive doses of insecticide that would normally be lethal to the majority of individu-als in a susceptible population of the same species [5]. In much of SSA, malaria vectors have developed resist-ance to all pyrethroid insecticides currently used in the treatment of ITNs [6–10]. Resistance has also expanded to other insecticide classes, particularly carbamates and organophosphates that are used for IRS, and incipient resistance to newly introduced insecticide classes such as pyrroles has appeared [11, 12].

WHO and the Roll Back Malaria Partnership have urged on governments of malaria-endemic countries, along with research and industry stakeholders, to adopt comprehensive strategies to address the growing threat of insecticide resistance and to foster the development of innovative vector control tools. In response, most SSA countries have developed and implemented insecticide resistance management (IRM) plans.

To support national malaria control programmes (NMCPs) in identifying key challenges and evidence gaps in decision-making for IRM, a multi-country case study was conducted. This study assessed the resistance monitoring and management landscape in Cameroon, mainland Tanzania, and Côte d'Ivoire, examining the alignment between national IRM plans and current epi-demiological conditions. In each country, the study was led by the NMCP staff responsible for vector control. Implementation was managed by Malaria Consortium,

and by the Centre for Research into Infectious Diseases (CRID) in Cameroon, the National Institute for Medi-cal Research (NIMR) in Mwanza, Tanzania, the Insti-tut Pierre Richet (IPR) in Côte d'Ivoire, all of which are partners in the RAFT (Resilience Against Future Threats) Research Programme Consortium, funded by UK Inter-national Development from the UK Government.

The study highlights that pyrethroid resistance is wide-spread, yet efforts to contain it are significantly ham-pered by funding constraints, limiting both the scale and effectiveness of current mitigation tools. While the study countries have national IRM plans in place, some are outdated and require revision to reflect evolving resist-ance patterns and programmatic realities. In response to growing resistance, countries are increasingly deploy-ing next-generation ITNs, especially those incorporating dual active ingredients, and tailoring strategies based on localized resistance profiles and malaria risk. However, core IRM approaches such as insecticide rotation play a diminishing role due to the declining use of IRS, pri-marily driven by reduced external funding. This trend demonstrates the pressing need for increased domestic investment in sustainable resistance management.

Importantly, the study was conducted prior to substan-tial funding cuts from major donors. In this context, the case studies provide critical insights that can strengthen IRM implementation by documenting best practices and generating actionable recommendations to enhance resistance monitoring and management in similarly affected settings.

Methods

Study design and country selection

This study employed a mixed-methods approach, inte-grating both qualitative and quantitative data collection techniques. Case studies were conducted in Cameroon, Côte d'Ivoire, and mainland Tanzania, located in cen-tral, western and eastern parts of Africa, respectively. These countries were selected based on the presence of the RAFT consortium partner organizations to facilitate the research, the burden of malaria and documented resistance challenges impacting national malaria control strategies, and the availability of entomological resistance data from research institutions and routine surveillance programmes.

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Climatic and demographic overview of study countries

Cameroon

Located in Central Africa, Cameroon covers an area of 475,650 km^2 and is divided into 10 administrative regions. The country exhibits considerable geographic and climatic diversity, with annual rainfall decreasing progressively from south to north. As of 2023, the estimated population is 28.8 million. Cameroon features three primary climatic zones: (i) *Equatorial climate*—abundant rainfall, a long rainy season (March to November), a short dry season (December to February). (ii) *Sudanese tropical climate*—rainy season from March to October, dry season from November to February. (iii) *Sahelian tropical climate*—long dry season (November to June) and a short rainy season (July to October). Annual rainfall ranges from 400 mm to 5000 mm [13].

Côte d'Ivoire

Situated in West Africa's intertropical zone, Côte d'Ivoire spans 322,462 km^2 and had an estimated population of 29 million in 2023 [14]. The population growth rate stands at 2.9%, with children under five making up 11% of the total. The nation's economy is heavily reliant on agriculture, and it is the world's largest cocoa producer. The country features three major climate types: (i) *Equatorial climate* in the south—high humidity, average temperatures of 26 °C, and two wet and two dry seasons. (ii) *Tropical climate* in the north—similar average temperatures but with greater daily variability and lower humidity. (iii) *Mountain climate* in the west—high rainfall, high humidity, and moderate temperatures around 24 °C, with distinct wet and dry seasons.

Tanzania

The United Republic of Tanzania comprises 31 administrative regions, with a total population of 61.7 million as of 2022 [15]. Twenty-six of the administrative regions are within mainland Tanzania. Most regions exhibit a tropical savanna climate, particularly in the eastern and western parts. Central areas are classified as arid steppe, while select regions in the northeast and southwest have a temperate climate [16]. Rainfall patterns are either bimodal or unimodal, depending on location. Areas such as the Lake Victoria Basin, the northern coast, and Mount Kilimanjaro have two rainy seasons. The central, southern, and western areas have one rainy season. Agriculture dominates the economy, with most people engaged in subsistence farming. Key rain-fed crops include rice, maize, oranges, and vegetables.

Data collection methods

The study was conducted in 2023. Data collection and analysis was carried out from April to December, which involved situation analyses, document reviews, and discussions with relevant stakeholders. For each country, national policies, malaria strategic plans, IRM policy documents, vector control strategic plans, NMCP reports, and other programmatic documents formed the basis of the document reviews. Additionally, published research and reports covering vector surveillance (including insecticide resistance trends and vector bionomics) as well as malaria epidemiological data, were analysed. Technical reports from malaria partners, and government and regulatory documents were also reviewed.

To contextualize malaria transmission dynamics, vector species distribution, and insecticide resistance profiles, a comprehensive situational analysis was conducted. Key aspects assessed included climatic, demographic, and socio-economic factors influencing malaria transmission and intervention feasibility; vector species and resistance patterns; the extent of insecticide resistance monitoring and frequency of entomological surveillance activities; vector control intervention coverage and funding; and logistical challenges.

Furthermore, structured interviews were carried out with key stakeholders involved in insecticide resistance monitoring and management. These stakeholders included NMCP staff, who provided insights into decision-making, implementation barriers, and the effectiveness of IRM policies; senior entomologists and researchers, who assessed methodologies for resistance monitoring and access to IRM data; vector control practitioners, who identified logistical constraints in intervention deployment and strategies for mitigating resistance; and health funding groups, who evaluated funding constraints, sources, and potential solutions to IRM-related gaps.

Data analysis approach

Data were analysed using both qualitative and quantitative methods. A thematic analysis was conducted to extract relevant insights from reviewed documents, focussing on key areas such as the clarity and specificity of IRM policies, the alignment between resistance data and strategic intervention planning, and gaps in stakeholder coordination, implementation guidelines, and decision-making processes.

In each country, two of the authors of this work (one from the NMCP and the other from a research institute) were involved in discussions with the relevant stakeholders and analysis to gain insights. The process was,

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however, not a formal interview using structured questions, but rather discussions using a checklist of main issues around the situations of malaria vector control and resistance management in each country. Stakeholder responses were examined to identify important themes related to IRM implementation challenges, policy effectiveness, and decision-making dynamics. Findings were categorized into common themes, including strengths, weaknesses, opportunities, and threats of existing IRM plans; bottlenecks in policy implementation; and stakeholder perspectives on gaps and challenges. A comparative analysis was conducted across the three countries to evaluate the effectiveness of the IRM plans. Findings were assessed to identify common challenges and country-specific factors influencing resistance management outcomes. The analysis aimed to extract best practices applicable to malaria-endemic regions with similar conditions, providing insights that could enhance resistance management strategies. Ethical approval was not sought as the study involved programmatic evaluation and did not engage human participants in a manner requiring formal review.

Results
Situation analysis
Epidemiological situation of malaria
Cameroon   Malaria remains a leading cause of morbidity in Cameroon. Between 2018 and 2022, parasite prevalence increased across all regions, rising from 24 to 26% nationwide [17]. Transmission levels vary by eco-epidemiological zones, influencing incidence rates. Among children under five, malaria incidence saw an initial rise between 2018 and 2020, followed by a 7% reduction, decreasing from 280 to 261 cases per 1000 children by 2022 [18, 19], The malaria mortality rate increased from 13.1 to 17.7 deaths per 100,000 inhabitants between 2018 and 2019, before declining to 9.0 deaths per 100,000 inhabitants by 2022. *Plasmodium falciparum* accounts for up to 95% of infections, while *P. malariae* and *P. ovale* contribute 1% and 3%, respectively [20]. These species appear either as mono-infections or in co-infections [21, 22]. Recent studies have also identified the presence of *P. vivax* in Cameroon [23–25].

Côte d'Ivoire   A national survey in 2021 found malaria infection prevalence to be 26% in Côte d'Ivoire [26]. The country defines four endemicity levels: low, medium, high, and very high, covering 17%, 28%, 36%, and 20% of the population, respectively. Approximately 56% of the people live in areas where annual malaria incidence surpasses 200 cases per 1000 inhabitants. Parasite prevalence among children aged 6–59 months declined from 37% in 2012 to 26% in 2022, highlighting shifts in malaria trans-

mission dynamics. *Plasmodium falciparum* dominates, accounting for over 95% of cases, while *P. malariae* and *P. ovale* appear less frequently, with *P. vivax* reported only in rare cases.

Mainland Tanzania   Similarly, malaria poses a significant public health challenge in Tanzania, ranking among the ten countries with the highest malaria morbidity and mortality. Prevalence fluctuates regionally and seasonally, shaped by environmental and climatic factors such as rainfall, temperature, and vector populations. Mainland Tanzania categorizes malaria risk into four epidemiological strata: very low, low, moderate, and high burden [27]. Confirmed malaria cases have declined substantially since 2015, dropping from 7.7 million cases to 3.5 million by 2022. Malaria incidence fell from 162 to 58 cases per 1000 population, while hospital admissions due to malaria declined from 529,146 cases in 2015 to 178,549 cases in 2022 [28]. Mortality rates dropped significantly, decreasing by 64% from 7.2 deaths per 100,000 in 2017 to 2.6 deaths per 100,000 in 2022 [28].

Overall, by 2022, nationwide malaria prevalence among children aged 6–59 months was 8% in Tanzania, 26% in Cameroon and Côte d'Ivoire (2021) [26, 27, 29]. Regional disparities remain significant, shaped by eco-epidemiological factors (Fig. 1). Mortality trends have varied, with Cameroon experiencing an increase between 2018 and 2019, followed by a decline in 2022 [30]. In Tanzania, malaria mortality rates decreased notably, falling between 2017 and 2022 [28]. Across all three countries, *P. falciparum* remains dominant [18, 19]. *Plasmodium malariae* and *P. ovale* persist as secondary contributors, found both as mono-infections or in co-infections. Reports of *P. vivax* have emerged in all three nations in recent years [23–25].

Malaria vectors bionomics
Distribution and abundance of vector species   Cameroon The principal vectors responsible for over 95% of malaria transmission in Cameroon include *Anopheles gambiae* sensu stricto (s.s.), *An. funestus*, *An. coluzzii*, *An. arabiensis*, *An. moucheti*, and *An. nili*. Secondary vectors contribute to malaria transmission on a localized scale, largely due to their low anthropophilic, limited abundance, and specialization to specific ecological niches [31–35]. Recent findings suggest that species, such as *An. multicinctus* and *An. demeilloni* can harbour *Plasmodium* parasites, although their role in human malaria transmission remains uncertain [12, 36].

Côte d'Ivoire
In Côte d'Ivoire, the main malaria vectors include *An. gambiae* s.s., *An. coluzzii*, *An. funestus* s.l. and *An. nili*.

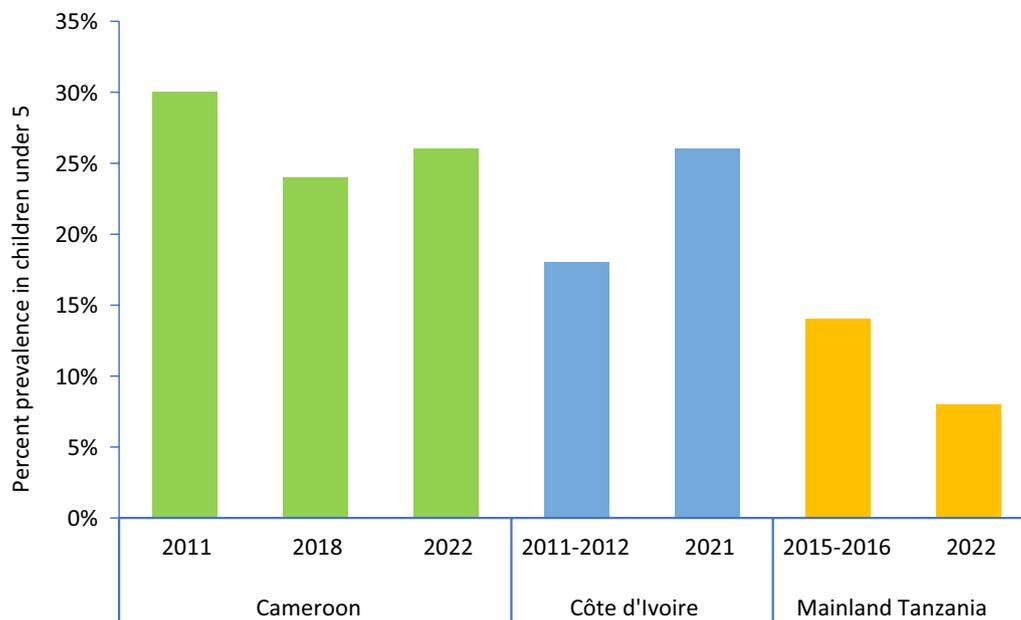Tabue *et al. Malaria Journal*   (2025) 24:375

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Fig. 1 Trends in malaria prevalence in children under five in Cameroon, Côte d'Ivoire, and mainland Tanzania

The *An. gambiae* complex species are particularly widespread and abundant, with *An. gambiae* s.s. more prevalent in the north and *An. coluzzii* predominating in southern regions [37, 38]. Some studies have identified *An. nili* as the most dominant vector in specific localities [39].

Mainland Tanzania

In mainland Tanzania, the dominant malaria vectors are *An. arabiensis, An. gambiae s.s., An. funestus* and *An. rivulorum.* Among these, *An. funestus* exhibits the highest degree of anthropophily, followed by *An. gambiae s.s.* and *An. arabiensis* [40]. A study conducted in 2021–2022 across ten sites in the Lake Zone revealed that *An. funestus* was the dominant vector in areas where IRS was not implemented (unsprayed areas) but was significantly reduced or absent in insecticide-sprayed sites, where only *An. arabiensis* and *An. gambiae* were collected; *An. funestus* accounted for 52% of all specimens collected, followed by *An. arabiensis* (39%), *An. gambiae s.s.* (8%), *An. merus* (0.3%) and *An. rivulorum* (0.1%) [41].

The distribution and composition of malaria vectors vary significantly across the three countries. Nonetheless, species within the *An. gambiae* complex consistently emerges as the most widespread and abundant.

Vector biting and resting habits

Malaria vector species in study countries breed in a wide range of larval habitats, from temporary stagnant pools to permanent or semi-permanent water bodies, with or without vegetation (Table 1).

Insecticide resistance   Cameroon

Recent surveys across 10 sentinel sites confirm resistance to pyrethroids in *An. gambiae* s.l. [12, 36, 43–45]. Pre-exposure to piperonyl butoxide (PBO) increased mortality rates, although full susceptibility was only restored in Djohong with alpha-cypermethrin and deltamethrin [12, 44]. High-intensity pyrethroid resistance and bendiocarb resistance were reported in most sites. *Anopheles funestus* s.l. exhibited pyrethroid resistance across all eco-epidemiological zones [46]. Carbamate resistance in *An. gambiae* s.l. has been documented since 2008 [46–48]. *Anopheles funestus* populations in these areas have also shown carbamate resistance [49]. As of 2022, resistance to clothianidin was confirmed in four sentinel sites and suspected chlorfenapyr resistance in three, including confirmed resistant populations in Sangmélima [12, 45]. Recent studies showed that *An. funestus s.l.* remains susceptible to both chlorfenapyr and clothianidin [50, 51].

Côte d'Ivoire

In Côte d'Ivoire, resistance monitoring has primarily focused on *An. gambiae s.l.,* which has shown resistance to pyrethroids, carbamates, DDT, and organophosphates across the country. Resistance to neonicotinoids and pyrroles has also been observed in certain localities [6, 7, 11, 52]. Synergist-based assays failed to fully restore susceptibility to pyrethroids, indicating an involvement of

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Table 1 Malaria vectors and their distribution and habits as of 2022. [22, 38, 42]

Country	Species	Vector status	Geo-graphical distribution in the country	Biting and resting habits		Key larval habitats*	Seasonality
				Resting behaviour	Biting behaviour		
Cameroon. [22]	*An. gambiae*	Primary	Countrywide	Both indoors and outdoors	Both indoors and outdoors	1, 2, 7	Year-round
	An. coluzzii	Primary	Countrywide	Both indoors and outdoors	Both indoors and outdoors	3, 7, 16, 18	Year-round
	An. arabiensis	Primary	Sahelian and savannah	Outdoors	Outdoors	1, 2, 7, 10	Rainy season
	An. funestus	Primary	Countrywide	Indoors	Indoors	10, 15	Year-round
	An. moucheti	Primary	Forest	Both indoors and outdoors	Both indoors and outdoors	12, 13	Year-round
	An. nili	Primary	Countrywide	Outdoors	Both indoors and outdoors	12, 13	Year-round
Côte d'Ivoire. [42]	*An. gambiae* s.l	Primary	Countrywide	Indoors	Both indoors and outdoors	1, 2, 4, 5, 6, 7	Rainy season
	An. funestus s.l	Primary	Countywide		Both indoors and outdoors	1, 2, 3, 6, 8	Rainy season and dry season in some localities
	An.nili s.l	Secondary			Both indoors and outdoors	8	Rainy season
Mainland Tanzania. [38]	*An. funestus*		Countrywide	Indoors	Indoors		
	An. gambiae s.s		Countrywide	Indoors	Indoors		
	An. arabiensis		Countrywide	Both indoors and outdoors	Both indoors and outdoors		

***List of larval habitats: 1** Rain pools/puddles, 2 Foot/hoof prints, 3 Swamps, 4 Lake shores, 5 Ponds, 6 Burrow pits, 7 Manmade water pools for brick-making and construction, 8 Drainage, 9 Seepages, 10 Rice fields, 11 Irrigated surface, 12 Small irrigation water canals, 13 Stream/river beds, 14 Pools on river banks, 15 Brackish water pools with vegetation/mangroves, 16 Water reservoirs/cisterns/wells/drinking water containers, 17 Tyres, 18 Discarded containers/flower vases

metabolic resistance. High-intensity resistance was also detected in multiple sites.

Mainland Tanzania

In mainland Tanzania, 2022 surveillance revealed widespread resistance of *An. gambiae s.l.* to deltamethrin, permethrin, and alpha-cypermethrin. Resistance to pirimiphos-methyl was also observed in all 10 sentinel districts, while no resistance was detected against clothianidin. High-intensity resistance to pyrethroids was identified Kakonko and Kibondo. PBO pre-exposure generally restored susceptibility, except in Kibondo, where suspected permethrin resistance persisted [53]. *Anopheles funestus* s.*l.* also showed resistance to pyrethroids and a lesser extent pirimiphos-methyl.

In summary, comparative findings across the three countries highlight widespread and intense pyrethroid resistance in *An. gambiae s.l.* [9, 45, 52]. While pre-exposure to PBO largely resulted in fully susceptibility in Tanzania [53], only partial restoration was noted in Cameroon [12]. *Anopheles funestus s.l.* exhibited resistance to pyrethroids and pirimiphos-methyl in Tanzania. *Anopheles funestus s.l.* was found to be resistant to pyrethroids and pirimiphos-methyl in mainland Tanzania [28], and

to carbamates in Cameroon [49]. Resistance to carbamates and organophosphates was observed in *An. gambiae s.l.* in both Côte d'Ivoire and Cameroon [12, 36, 45]. Resistance to neonicotinoids and pyrroles has also been observed in Côte d'Ivoire [6, 7, 52] and Cameroon [12, 45], while full susceptibility to clothianidin was preserved in Tanzania [28]. In Cameroon, *An. funestus s.l.* remains susceptible to chlorfenapyr [50] and clothianidin [51].

Target-site resistance remains the most extensively studied mechanism in all three countries. The *kdr*-West L1014F mutation is highly prevalent in Côte d'Ivoire and Cameroon, while the *kdr*-East L1014S variant appears at low frequencies [7, 11, 12, 52, 54–56]. The G119S *Ace*1 mutation, associated with carbamate and organophosphate resistance, has been reported in *An. gambiae* s.l. [12, 45]. In Tanzania, L1014S was more common in *An. arabiensis*, while L1014F was only detected in Kakonko, in both *An. arabiensis* and *An gambiae s.s.* [53]. The A296S-RDL mutation conferring resistance to dieldrin was detected at a frequency of 90% in Cameroon [54, 57–60].

Metabolic resistance is associated with overexpression of detoxification enzyme gene families: cytochrome P450s, glutathione S-transferases (GSTs), and esterases.

In *An. gambiae* s.l. from Cameroon, P450 genes linked to resistance include CYP6P3, CYP6M2, CYP6Z1, CYP6Z2, CYP6P4, CYP6P5, CYP9K1 [61, 62]; while GST genes include GSTe2, GSTD3, and several variants of GSTD1. In *An. funestus*, resistance-related genes comprise CYP6P5, CYP6M7, CYP6P9a and CYP6P9b, CYP325A [12, 36, 63] and Gste2 [57, 59]. Metabolic resistance has also been documented in Côte d'Ivoire [7].

Coverage of vector control interventions

Insecticide-treated nets   Cameroon

In Cameroon, stratification of ITN types by district for the 2022–2023 mass distribution campaign was guided by epidemiological and entomological data. Three ITN types (pyrethroid-only, pyrethroid-PBO and dual active ingredient ITNs) were adopted for both routine and mass distribution. For the mass campaign, a total of 10,424,700 ITNs were acquired, comprising 49% PBO nets, 27% dual active ingredient nets, and 24% pyrethroid-only nets [64].

Côte d'Ivoire

The 2021 mass campaign distributed 18,509,750 ITNs, including 67% pyrethroid-only ITNs (deltamethrin or alpha-cypermethrin), 17% pyrethroid-PBO ITNs (with deltamethrin), and 17% pyrethroid-chlorfenapyr nets. To maintain universal coverage, additional distribution channels were introduced beyond ANC and EPI. These include schools, community outreach, and social marketing guided by the newly developed national guidelines for continuous distribution of ITNs. However, as of 2022, only a pilot school-based distribution was conducted in the Abidjan district and surrounding suburbs.

Mainland Tanzania

In mainland Tanzania, ITNs are distributed using multiple channels [65]. In 2022 alone, a total of 22,843,200 ITNs were distributed [28]. A retrospective cross-sectional survey conducted that year revealed that 27% were pyrethroid-PBO and 73% were pyrethroid-only nets [66]. The survey also highlighted variability in insecticidal efficacy across different ITN brands, underscoring the need for stringent pre-shipment and pre-distribution quality control. ITNs in use for up to 2.5 years remained in good and serviceable condition, leading investigators to recommend a replacement interval of 2.5 years [66]. However, several challenges affected implementation, including poor alignment between commodity delivery and campaign execution pipelines, sub-optimal physical and chemical durability of nets, widespread insecticide resistance, and low ITN use rates [28].

In all three countries, ITN distribution is implemented through both mass campaigns and routine channels. A comparative analysis of ITN ownership and usage across Tanzania, Cameroon, Côte d'Ivoire, and Tanzania offers valuable insights into the progress achieved and the gaps that remain in malaria prevention efforts [26, 27, 29]. Although household ownership and access to ITNs remain generally high, the target of ensuring that 80% of the population has access to ITNs has not yet been fully achieved. Moreover, notable disparities persist between access to ITNs and their actual usage across countries, as illustrated in Fig. 2.

Indoor residual spraying   Cameroon

Unlike Tanzania and Côte d'Ivoire, IRS is not implemented in Cameroon.
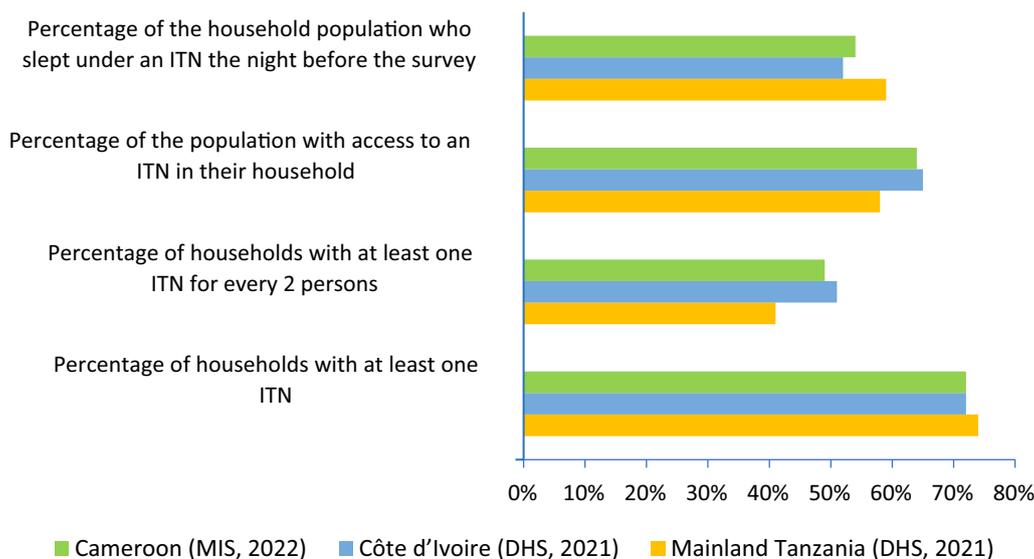

Fig. 2 ITN coverage and use indicators in study countries [26, 27, 29]

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Côte d'Ivoire

IRS was confined to two districts (Sakassou and Nassian) due to budget limitations. These districts were selected based on entomological and malaria incidence data. Since 2018, insecticide resistance and residual efficacy studies supported the use of clothianidin for IRS. Although entomological data indicated that IRS campaigns should occur between April and May to coincide with peak malaria transmission, the 2020 and 2021 campaigns were conducted later, in August and September. The 2022 IRS campaign occurred slightly earlier, in June and July [6].

Mainland Tanzania

In mainland Tanzania, IRS has been used since 2006, funded by the US President's Malaria Initiative (PMI) [28, 40, 67]. The coverage and choice of insecticide has varied over time. Initial IRS target areas were selected in response to recurrent malaria epidemics in 2006 and 2007. Subsequently, implementation expanded to additional district councils within the Lake Victoria basin. However, from 2012–2013 coverage declined. The 2021 IRS plan aimed to cover approximately 550,000 strictures across six districts in Kigoma, Geita, Kagera and Mwanza regions [28, 40, 67]. Despite targeting 30 councils and 1,783,790 structures, only six councils were reached. Due to funding shortfalls, the programme was further scaled back to just two councils in 2022, spraying 241,470 structures. Statistical analysis of monthly malaria incidence data demonstrated a significant decline during periods of IRS implementation. Conversely, malaria cases surged in nearly all districts where IRS was withdrawn, underlining the intervention's impact [40]. IRS coverage across mainland Tanzania was limited due to financial constraints.

In both Côte d'Ivoire and Mainland Tanzania, IRS coverage has seen reductions over the years. Consequently, malaria resurgence has been observed in some areas where IRS was withdrawn.

Larval source management Larval source management (LSM) has not been widely implemented in Côte d'Ivoire and Cameroon. In 2022, 343,288 people in Côte d'Ivoire were protected through the treatment of stagnant water near homes using *Bacillus thuringiensis israelensis* serotype H14 (VectorBac WC 500) (Côte d'Ivoire NMCP data). In Cameroon, between 2018 and 2020, a total of 12,688 kg of *Bacillus thuringiensis* var. *israelensis* (*Bti*) and *Bacillus sphaericus (Bs)* was applied to breeding sites across 13 neighbourhoods in Yaoundé [68]. In contrast, Tanzania has implementing LSM consistently since the mid-2000s, initially focussing on selected wards in Dar es Salaam. Since 2021, approximately 19,975 L of larvicides (*Bti* and *Bs)* have been used to target mosquito breeding habitats in three councils within the Tanga region [28].

Insecticides registered for public health use

Due to the extensive use of pesticides in agriculture, responsibility for pesticide registration lies with the Ministry of Agriculture in all three countries. Each ministry has a technical body overseeing pesticide regulation: the Tanzania Plant Health and Pesticides Authority in Tanzania, the Pesticide Committee in Côte d'Ivoire, and the Department of Regulation and Quality Control of Agricultural Inputs and Products in Cameroon. These entities are tasked with regularly updating the list of approved pesticides.

In Cameroon and Côte d'Ivoire, herbicides account for 50–65%% of imported pesticides, while insecticides make up 23–26%. In Côte Ivoire, approximately 76% of insecticides used belong to the pyrethroid class. In Tanzania, the most widely sold agricultural insecticides include pyrethroids (e.g., lambda-cyhalothrin) and neonicotinoids (e.g. imidacloprids) [52, 69].

Prioritization and targeting of vector control interventions

Under the High Burden to High Impact (HBHI) approach, all three countries have stratified malaria risk based on parasite prevalence, malaria incidence, and all-cause mortality in children under five. This stratification has guided the tailoring of intervention mixes to maximize impact [20, 28].

In terms of vector control, the countries have implemented multiple types of ITNs in mass campaigns. This marks a shift away from uniform ITN distribution towards approaches that consider the insecticide resistance profiles of local malaria vectors. In Côte d'Ivoire and Tanzania, IRS has been deployed in high-risk zones to further reduce malaria transmission.

Vector control programme structure and capacity

According to information gained from the NMCPs, the structure of the malaria vector control programme is broadly similar across the three countries. Each has a vector control unit responsible for developing strategic plans and decision-making in alignment with WHO guidelines. The NMCPs are supported by national consultative bodies for vector control: the Vector Control Technical Working Group (VCTWG) in both Tanzania and Côte d'Ivoire, and the Technical Vector Control Committee Group (TVCCG) in Cameroon. These groups operate under official decrees, with defined memberships and regular meeting schedules. They serve as platforms to deliberate on innovative strategies

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or policy shifts, with recommendations forwarded to the Ministry of Health for action.

Human resource assessments show a significant gap in mainland Tanzania, where 184 personnel are needed (one per administrative council) but only 32 are available, leaving an 83% shortfall. In Cameroon and Côte d'Ivoire, the available human resource capacity was deemed sufficient to some extent.

Stakeholder analysis

Vector control programmes engage a broad range of stakeholders, particularly in insecticide resistance monitoring and management. These include ministries such as agriculture and livestock development, which oversee pesticide use in crop and livestock protection.

National research institutions and universities provide technical expertise and collect data to inform decision-making. International partners like the WHO offer policy guidance, while donors such as the Global Fund and PMI have been providing essential financial support for resistance monitoring activities and implementation of vector control interventions.

Evaluation of the national IRM plans
General observations

All three countries have developed IRM plans that cover periods of 4–5 years (Table 2). Cameroon's current plan spans 2021–2025, while Tanzania and Côte d'Ivoire implemented their most recent plans for 2016–2020 and 2017–2020, respectively [70, 71]. Updates to the IRM plans in Tanzania and Côte d'Ivoire are pending. Each plan is aligned with both the national malaria strategic plans and the Global Plan for Insecticide Resistance Management (GPIRM) [72], sharing the common objective of preserving the efficacy of insecticidal vector control interventions by promoting implementation of appropriate interventions and mitigating the development of resistance.

The IRM plans advocate for a multi-strategy approach to resistance management, emphasizing the concurrent use of interventions with proven effectiveness to slow the spread of resistance. In general, resistance management, in its strict sense, has largely focused on rotating insecticides for IRS and deploying dual-insecticide ITNs at a limited scale. However, the implementation of IRS has either been discontinued or confined to select regions, primarily due to the rising cost of insecticides. Initiatives to introduce LSM using bacterial larvicides and the increased use of dual-insecticide ITNs targeting areas most in need of the interventions could contribute to efforts to manage resistance, but the available options remain limited. Each country has tailored its strategy based on the predominant vector control tools in use. In Tanzania and Côte d'Ivoire, the IRM plans

Table 2 Summary of the evaluation of IRM plans of Cameroon, Côte d'Ivoire, and Mainland Tanzania

Evaluation type	Cameroon	Côte d'Ivoire	Mainland Tanzania
General			
IRM plan's period	2021–2025	2017–2020	2016–2020
Up-to-date plan	Yes	No	
Alignment with malaria strategic plan	Yes		
Alignment with WHO's GPIRM	Yes		
Vector control interventions	ITNs	ITNs, IRS, LSM	
Adequacy of resources			
Budget gaps	Significant reliance on external funding, but a significant number of activities implemented	Significant reliance on external funding	
Human resource gaps	Sufficient to a limited extent	Insufficient	
Equipment gaps	Lack of equipment for entomological monitoring at sentinel sites, dependence on research institutions and universities, and lengthy and cumbersome procurement processes	Lack of equipment for entomological monitoring; dependence on research Institutions and universities	
Implementation of the plan			
Plan implementation and use as intended	Limited to tailoring of different ITN types to be distributed according to epidemiological and resistance profiles; 40% of functional sentinel sites and 45% of planned activities completed	Tailoring of different ITN types to be distributed according to epidemiological and resistance profiles; selection of IRS insecticides based on resistance profiles; and limited IRS geographical coverage; some rotation of insecticides	
IRM decision-making process	Through the support of technical vector control committees or group		

outline resistance management strategies related to IRS implementation, while addressing approaches for making appropriate choices of ITN types based on resistance and malaria transmission levels. In Cameroon, where ITNs remain the principal vector control tool, a stratification approach was introduced in 2021 to allocate ITN types according to insecticide resistance profile of each health district.

Needs assessments indicate that NMCPs lack sufficient vector control equipment and are heavily reliant on support from research institutions and implementing partners. In Cameroon, additional challenges include lengthy and complex procurement processes. Despite these barriers, all three countries strive to align their interventions with epidemiological and entomological evidence. The selection and deployment of vector control tools are driven by resistance profiles and, to a large extent, guided by IRM plan recommendations.

While financial constraints often limit the full implementation of IRM plan activities, each plan includes a monitoring and evaluation (M&E) framework with defined indicators to track progress and inform adjustments.

Opinions of experts and partners on IRM plans

Despite the adoption of insecticide resistance management strategies widespread insecticide resistance continues to be reported across vector populations in all three countries. This persistent trend partly indicates that resistance selection pressure is not yet adequately mitigated. Strengthening resistance management requires the judicious and timely deployment of effective interventions such as IRS and ITNs. Additionally, reinforcing national pesticide regulation is critical for enhancing IRM efficiency.

A SWOT (strengths, weaknesses, opportunities, and threats) analysis based on expert opinions and document reviews offered valuable insights into the implementation of national IRM plans.

Strengths   The existence of a 5-year IRM plan provides a structured and strategic framework for resistance monitoring and management. Established sentinel sites support entomological surveillance, enabling regular data collection on vector populations. Strong collaboration between NMCPs and research institutions enhances data analysis and supports evidence-based decision-making.

Weaknesses   Intersectoral collaboration remains weak, limiting cohesive efforts across health, agriculture, and environmental sectors. Inadequate financial resources hamper the full execution of planned activities and the procurement of essential vector control tools. Limited

data on resistance mechanisms and weak genetic surveillance systems hinder rapid detection and response strategies. A shortage of trained personnel, technical expertise, and infrastructure affects the quality and reach of entomological monitoring. There is a critical data gap regarding resistance in secondary vector species, which limits comprehensive resistance assessments.

Opportunities   Continued support from international partners offers both technical and financial resources that can be leveraged to strengthen IRM efforts. Growing regional and global attention on vector-borne disease control may catalyse additional investments and innovations.

Threats   Persistent underfunding for vector control and heavy reliance on external aid threaten the long-term sustainability of IRM activities. The limited use of LSM (and integrated vector management in general) in resistance management, and availability of only few options of newer insecticides has been a challenge that could threaten effective resistance management. The further spread of resistance among malaria vectors could significantly undermine vector control interventions. Regional and geopolitical instability risks diverting financial and technical resources away from public health priorities. Climate change is altering vector ecology, compounding the challenges of resistance management. The emergence and spread of invasive vector species, such as *Anopheles stephensi*, may necessitate rapid adaptations to existing control strategies.

In addition to the SWOT analysis, several good practices have emerged, including: (a) utilization of resistance data to inform LLIN distribution and IRS insecticide selection; (b) regular updating of national entomological profiles; (c) presence of technical consultative groups that support NMCPs in vector control decision-making; (d) existence of regulatory bodies to oversee pesticide approval and use; and (e) development of robust surveillance systems for monitoring insecticide susceptibility in malaria vectors.

However, challenges remain. Across all three countries, the number of sentinel surveillance sites is insufficient, and the shortage of medical entomologists hampers effective monitoring and response. A common barrier is weak intersectoral coordination such as with the agricultural sector, largely due to the absence of formal multisectoral committees for resistance management. In agricultural sectors, the unregulated use of pesticides exacerbates resistance development. Although the role of intense use agricultural pesticides in the development and expansion of resistance in malaria vectors is unclear, information sharing and cooperation will be required

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between the health and agricultural sectors. Furthermore, chronic underfunding and dependency on donor support limit consistent IRM plan implementation. This reflects a broader issue of limited national ownership and commitment.

Discussion

The case studies in Cameroon, Côte d'Ivoire and mainland Tanzania found that all three countries had developed IRM plans to guide their efforts to mitigate resistance threats to the effectiveness of vector control efforts. Although the IRM plans for Côte d'Ivoire and Tanzania have expired and are pending updates, all three IRM plans are well aligned with their respective national malaria strategic plans and with WHO global frameworks and recommendations. Nevertheless, a comprehensive review of national documents and data and interviews with key stakeholders found that the implementation of the IRM plans has been sub-optimal, primarily due to financial limitations. Each country remains heavily dependent on external funding to conduct resistance monitoring and deploy vector control interventions aimed at mitigating the effects of insecticide resistance.

While ITN campaigns have generally adopted a more targeted approach by distributing different net types based on entomological and epidemiological profiles especially since 2020, the use of IRS remains limited. Where IRS has been implemented, rotation of insecticides with different modes of action is scheduled to delay the development and spread of resistance.

IRM implementation challenges

A key challenge in implementing IRM plans in Cameroon, mainland Tanzania, and Côte d'Ivoire is the persistent shortage of domestic financial resources and heavy reliance on donor funding. This dependence exposes national vector control programmes to significant risks, as external support can be unpredictable and unsustainable. In 2021, nearly half of SSA countries relied on external financing for over one-third of their health expenditures [73]. By 2022, only about half of the global financial needs required to maintain progress against malaria were met [74], due in part to competing global priorities, geopolitical instability, and climate change.

In all three countries, funding shortfalls have contributed to suboptimal implementation of IRM activities. Coverage of vector resistance monitoring remains weak; although sentinel sites have been identified, many remain inactive due to lack of funding. Budget constraints have also led to reductions in the scope of core interventions such as IRS and ITN distributions.

Insecticide resistance monitoring and vector control efforts have so far been largely funded by the Global Fund and PMI. In fact, between 2010 and 2023, the US alone accounted for an average of 37% of global malaria funding through bilateral and multilateral channels [1]. Any disruption to this support (such as the recent suspensions) poses a major threat to the continuity of essential activities, as has been observed in past instances of donor withdrawal [75].

To reduce vulnerability and ensure long-term sustainability, countries must increase domestic investment in malaria control, although it is acknowledged that the funding gap to be bridged is substantial and will require major new financial commitments. Strengthening national ownership and resource mobilization will be key to maintaining and scaling insecticide resistance management and broader vector control efforts.

Resource gaps are likely to have serious implications for the effectiveness of vector control interventions. These challenges span three interrelated components of resistance management:

a. *Resistance Monitoring*: Understanding the geographic distribution and underlying mechanisms of insecticide resistance is essential for informed decision-making. Effective resistance management depends on surveillance systems that capture data from a representative range of epidemiological settings. Expanding the number of sentinel surveillance sites is critical to improving the granularity and reliability of entomological data for localized intervention planning.
b. *Deployment of new-generation ITNs*: As resistance intensifies, more areas require the use of next-generation nets, particularly those incorporating dual active ingredients. To ensure these high-value tools are targeted appropriately, robust local data on resistance profiles and malaria risk is essential. Scaling up their use will also require significant additional funding.
c. *Use of IRS*: IRS coverage has declined over time, largely due to rising costs of newer insecticides and stagnating or reduced funding. Although IRM strategies recommend annual or biennial insecticide rotation to delay resistance development, broader IRS coverage could further strengthen resistance management by introducing additional modes of action complementary to those in ITNs. Strategic use of IRS remains essential to preserving the efficacy of limited novel chemistries used in dual active-ingredient nets.

Public–private partnerships in malaria vector control

Working with the private sector could offer a critical opportunity to complement limited external resources in malaria control efforts. Companies operating in various

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industries such as mining, oil, timber, and natural gas can have important roles in malaria control. Public–private partnerships have played a valuable role in the implementation of IRS and distribution of ITNs in several countries [76–80]. Such investments not only protect surrounding communities and contribute to implementation of interventions that help in mitigation of insecticide resistance, but also yield returns for companies by reducing productivity losses associated with staff absenteeism and turnover caused by malaria [81, 82].

The private sector has contributed significantly to innovation, with initiatives like the Innovative Vector Control Consortium playing a key role in developing new insecticides for malaria control [83]. To harness this potential more systematically requires actively identify private sector partners and encouraging their participation in malaria control. Introducing incentives such as tax breaks could further motivate sustained private investment in public health initiatives.

Subnational tailoring of malaria vector control interventions

WHO's HBHI initiative, launched in 2018, targets 11 countries that accounted for 70% of the global cases and 71% of malaria-related deaths [84]. Central to the HBHI framework are four response pillars, one of which focuses on harnessing strategic information to maximize impact.

A key development within the HBHI strategy is the wider introduction of subnational tailoring (SNT) of malaria control interventions rather than uniform deployment of tools nationwide. SNT involves using localized data (such as epidemiological, entomological, climatic, and financial information) to select the most appropriate combination of interventions for a given area. The goal is to optimize disease control outcomes based on the specific transmission dynamics and contextual realities within each subregion using a specific resource envelope [85].

One successful practice observed is the stratification of vector control measures. For example, this study found that ITNs are distributed largely according to the insecticide resistance profile of malaria vectors in different regions of Cameroon [64]. Similarly, IRS is implemented in targeted areas based on resistance patterns and transmission intensity [28, 40, 67]. SNT also supports the implementation of integrated vector management (IVM), a coordinated approach that combines ITNs, IRS, and LSM to address the multifactorial nature of malaria transmission. Evidence shows that effectively integrated interventions reduce malaria incidence significantly and help delay the development of insecticide resistance [86, 87].

However, resource constraints often limit the full deployment of all interventions. Many of the stakeholders interviewed identified that flexible and scenario-based planning is essential, ensuring that strategies can be adapted according to available resources. As with all modelling efforts, the success of this approach hinges on the quality and availability of data, which remains a challenge in many settings.

Political will

In March 2024, ministers from high-burden African countries endorsed the Yaoundé Declaration, reaffirming their dedication to reducing malaria-related mortality and outlining priority actions to accelerate progress towards global malaria elimination goals [88]. However, the effectiveness of such declarations depends on their translation into concrete actions sustainable political will. This need has become even more critical in light of reduced or suspended donor funding. In response of these challenges, some countries, such as Nigeria, have proactively increased domestic financing to mitigate the impact of funding shortfalls [89].

Best practices in IRM implementation
Using resistance data to guide vector control deployment
The introduction of the HBHI approach has encouraged malaria-endemic countries to tailor vector control strategies at the subnational level within their national malaria plans [90–93]. Many others have also adopted this shift from "business-as-usual" mindset. In mainland Tanzania, continuous resistance monitoring between 2004 and 2020 led to the rollout of PBO-treated nets, which enhance the efficacy of pyrethroids against resistant mosquito populations [9]. In Kenya, resistance surveillance has informed ITN replacement strategies and adjustments in IRS insecticide choices, following declines in mortality among *An. gambiae s.l.* due to resistance and chemical degradation [94]. A multi-country study conducted in Sudan, Kenya, India, Cameroon, and Benin further illustrated how losses in the epidemiological effectiveness of ITNs and IRS, driven by insecticide resistance, can inform tailored approaches [95]. These examples reflect how entomological data now shape national malaria strategies across Africa. Increasingly, donors require evidence-based stratification as part of funding applications, demanding more targeted interventions. At least 28 countries have integrated components of SNT to inform submissions to the Global Fund and GAVI [85, 96].

Establishing strong resistance monitoring systems
For many years, pyrethroids were the sole insecticide class used in ITNs due to their low toxicity in humans.

Recently, dual-active ingredient nets combining pyrethroids with other chemicals such as pyrroles (chlorfenapyr) have been introduced [97]. For IRS, after decades of reliance on DDT and pyrethroids [98], control programmes have transitioned to carbamates, organophosphates, and newer classes such as neonicotinoids (clothianidin), meta-diamides (broflanilide), and isoxazolines (isocycloseram) [99–101]. GPIRM recommends several strategies for managing vector resistance insecticides [14]. However, effective IRM relies on accurate knowledge of local resistance profiles, which requires strong entomological surveillance systems. Yet, surveillance remains patchy. Moyes et al. (2019) found that 89% of districts across Africa lacked resistance data for years between 2015 and 2017, showing a weak entomological surveillance system in many countries [102]. Thanks to PMI support, several countries have made notable improvements in data collection [12]. These developments coincide with the launch of the HBHI and the scale-up of sentinel surveillance systems to monitor vector behaviour and resistance. Nevertheless, once again, several countries have had to scale down some of their entomological surveillance activities due to donor withdrawal of funds at the time when the need for such data has become crucial for local tailoring of interventions.

Governmental oversight of effective pesticide management
In many SSA countries, pesticide regulation remains weak, marked by limited monitoring, insufficient regulatory frameworks, and heightened public health risks. The manufacture, distribution, and use of pesticides often occur without adequate safeguards. Government regulatory agencies are key to addressing this challenge. Their role extends beyond product registration to encompass quality control, import/export monitoring, labelling oversight, and post-market surveillance. In the case study, Cameroon, Tanzania, and Côte d'Ivoire have established regulatory bodies housed within their ministries of agriculture. Other examples include the National Agency for Food and Drug Administration and Control in Nigeria, the Kenya Plant Health Inspectorate Service in Kenya, and the Zambia Environmental Management Agency.

The choice of vector control products is guided not only by resistance profiles but also by the WHO prequalification list. Many countries rely on this list as donors require countries to purchase only WHO-prequalified brands. This ensures safety, quality, and efficacy, giving confidence that products used are capable of protecting communities and mitigating resistance risks.

Limitations of the study
The analysis of the epidemiological and entomological contexts reported in this paper had to rely on limited data sources in each country, especially regarding insecticide resistance and malaria incidence. Some of the data were not readily available to provide a more comprehensive picture of the transmission dynamics and evolution of resistance covering different eco-epidemiological settings.

The development of the IRM plans assessed in each country were steered by the NMCPs with technical contributions of research partners and donor communities. The fact that the analysis of the level of implementation of the plans was carried out by NMCP members and researchers involved in their development may have introduced a bias in the assessment process. However, the process was considered as a self-evaluation that was designed from the start as such. This would facilitate the implementation of the recommendations of the analysis by the NMCPs and their partners as the work represented internal assessment of strengths and drawbacks rather than as an external evaluation.

Conclusion
Insecticide resistance continues to compromise the efficacy of malaria vector control strategies, highlighting the critical need for robust, adaptive IRM plans. Data from Cameroon, mainland Tanzania, and Côte d'Ivoire confirm that resistance is not only persistent but also widespread. Yet, current containment efforts remain limited in both scope and effectiveness. The shortcomings stem from several interrelated factors, including insufficient resources to effectively implement the plans, due to lack of means to map and understand the geographic distribution of resistance, inadequate surveillance systems with limited geographic coverage, and limited funding for the deployment of new tools in a cost-effective manner. Additionally, there is a pressing need to scale up proven interventions such as IRS to mitigate the spread and impact of resistance more effectively.

Comprehensive local data on distribution, intensity, mechanisms, and impacts of insecticide resistance are critical for informed decision-making. More than ever, tailoring interventions to local needs through cost-effective strategies is essential. Gaps in essential resources were already found to have posed a significant challenge to the effectiveness of vector control interventions in the period when this assessment was conducted. Recent funding changes only serve to make this challenge several magnitudes larger. The successful deployment of high-impact but relatively more

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expensive tools, such as new-generation ITNs, depends on evidence-based selection and strategic targeting.

National IRM plans must be both regularly updated and realistically aligned with funding landscapes, especially considering rapidly evolving resistance patterns and dynamic programmatic challenges. These plans should move beyond static frameworks and embrace adaptive, evidence-based approaches to resistance management. Their evolution must prioritize securing sustainable domestic financing and enhancing coordination across sectors in order to build resilient and responsive vector control programmes.

Postscript

This study was conducted in 2023 prior to the substantial aid reductions by the US government and other key international donors.

Abbreviations

AI	Active ingredient
ANC	Antenatal care
Bs	Bacillus sphaericus
Bti	Bacillus thuringiensis var. israelensis
CDC	Centre for Disease Control and Prevention
CRID	Centre for Research into Infectious Diseases
EPI	Expanded Programme on Immunization
GPIRM	Global Plan for Insecticide Resistance in Malaria vectors
HBHI	High burden to high impact
IPR	Institut Pierre Richet
IRM	Insecticide resistance management
IRS	Indoor residual spraying
ITN	Insecticide-treated net
IVM	Integrated vector management
LSM	Larval source management
MVES	Malaria Vector Entomological Survey
NIMR	National Institute for Medical Research
NMCP	National Malaria Control Programme
PBO	Piperonyl-butoxide
PMI	US President's Malaria Initiative
RAFT	Resilience Against Future Threats through vector control
RBM	Roll Back Malaria
TVCCG	Technical Vector Control Committee Group
VCTWG	Vector Control Technical Working Group
WHO	World Health Organization

Author contributions

TAA conceived the study, with contributions from JL and SC. The case study reports on which the manuscript was based was prepared by RNT, CGNG, CDM, PKT, BKF, and EE-N, led by TAA and with contributions of RZW, BM and JM. The draft manuscript was prepared by RNT and revised by TAA, with additional inputs of all other co-authors. All authors have read and approved the manuscript for publication.

Data availability

The datasets generated and/or analysed during the current study are secured at the national malaria control programmes of Cameroon, Côte d'Ivoire, and Tanzania. These data are available upon reasonable request from the directors of national malaria control programmes.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
All the authors approved the final version of the manuscript for publication.

Competing interests
The authors declare no competing interests.

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