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Trends in Parasitology

Opinion

Safeguarding malaria control gains in Africa through 'species sanitation' and structural resilience

Fredros Okumu [1,2,*], Joel O. Odero [1,2], J. Derek Charlwood [3], Bart G.J. Knols [4], and April Monroe [5,6]

To maintain effective malaria control, endemic countries must reinforce their short-term commodity-based approaches with sustainable, longer-term strategies. In Africa, where only a few highly-efficient *Anopheles* vectors drive most malaria transmission, we propose a two-tier strategy to safeguard control gains. First, aggressively pursue an expanded interpretation of species sanitation by targeting ecological vulnerabilities of primary vectors to suppress or eliminate them. Second, gradually build structural resilience through improved housing and environmental management. Future innovations, like gene-drive mosquitoes and longer-lasting vaccines, could further amplify impact and enhance resilience in poor communities. This layered strategy must rest on human-centred policies, increased domestic funding, cross-sector partnerships and resilient health systems, anchored in longer-term planning beyond the usual 5-year cycles. Ultimately, countries could preserve control gains, despite limited external financing.

Highlights

Malaria control in Africa must become more efficient and sustainable, a reality amplified by recent funding shocks.

We propose a dual approach consisting of (i) species sanitation, that is, targeted suppression of primary vectors based on detailed ecological understanding for immediate impact, and (ii) structural resilience, that is, incremental housing and environmental improvements to lock in gains – supported by transformative technologies such as gene-drive mosquitoes and long-lasting vaccines.

This tired approach can be reinforced through human-centred programmes and policies, multisectoral collaboration, domestic financing, and stronger health systems.

As a foundational step, endemic countries should adopt longer-term strategic planning, beyond common 5-year cycles.

Over time, this layered approach can enhance and sustain malaria-control gains without overreliance on external aid.

Limitations of current malaria-control models

The most recent World Malaria Report underscores how challenging the fight against malaria has become [1]. Although deaths are decreasing in many countries, suggesting better access to effective treatment, the rate of improvement remains disappointingly slow. Even when viewed optimistically, the reality is that malaria case numbers are rising in many countries, indicating that preventive measures are inadequate. This is exacerbated by rising costs of essential health commodities and growing populations in endemic countries [2]. Furthermore, recent shifts in global funding, particularly the abrupt cuts in foreign assistance from the USA, formerly the leading contributor, along with reductions by European countries such as the UK and the Netherlands[i], highlight the urgent need to maximise the effective use of available resources; and to strategically build long-term resilience in malaria-affected countries.

Malaria persists due to complex environmental, economic, and social drivers. Poor housing enables mosquito entry, inadequate water management creates breeding sites, weak health systems limit consistent prevention and care, and social inequities heighten vulnerability. Unfortunately, efforts to address failures in malaria control in recent decades have largely focused on symptoms (e.g., drug resistance or insecticide resistance) rather than the underlying root causes. As a result, responses have concentrated on the development of new tools rather than fundamentally rethinking and redesigning strategic approaches [3].

Here, we propose a two-tiered strategy that harnesses fundamental vector ecology and behaviours to achieve practical and sustainable malaria prevention in Africa's low-income settings. The

[1]School of Biodiversity, One Health and Veterinary Medicine, G12 8QQ, University of Glasgow, Glasgow, UK
[2]Environmental Health and Ecological Science Department, Ifakara Health Institute, P.O. Box 53, Ifakara, Tanzania
[3]Global Health and Tropical Medicine, Instituto de Higiene e Medicina Tropical, Rua da Junqueira 100, Lisboa, Portugal
[4]K&S Consulting, Kalkestraat 20, 6669 CP, Dodewaard, The Netherlands
[5]Swiss Tropical and Public Health Institute, Kreuzstrasse 2, 4123, Allschwil, Switzerland

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goal is to achieve both immediate and sustained protection far beyond the current short-term intervention cycles that are mostly dependent on specific commodities. The approach comprises two core components: targeted control of primary vectors, informed by an understanding of their ecology (i.e., **species sanitation**) (see Glossary), and the gradual development and expansion of **structural resilience** within communities to reinforce and sustain the gains (Figure 1). Species sanitation in the context of malaria control means 'attention should be directed primarily to local anopheline mosquitoes known to be the principal transmitters of malaria' and should be guided by a clear understanding of their ecology and behaviours [4]. In this context, we refer to data-driven targeting certain important mosquito species aggressively, in their aquatic and/or adult life cycle stages [5]. In parallel, structural resilience focuses on long-term prevention strategies, including gradually improving housing and built environments to ensure communities' surroundings are unsuitable for *Anopheles* breeding and physically shield people from mosquito bites.

Our proposal, therefore, is that the overarching malaria-control strategy should extend beyond the health sector, engaging infrastructure, housing, finance, local government, environmental planning and other departments or sectors, to establish durable community-level barriers to transmission [4,6]. To be most effective, these strategies must also be long-term and integrated within the broader public health context, rather than treating malaria as an isolated disease.

[6]University of Basel, Petersplatz 1, 4001, Basel, Switzerland

*Correspondence:
fredros.okumu@glasgow.ac.uk
(F. Okumu).

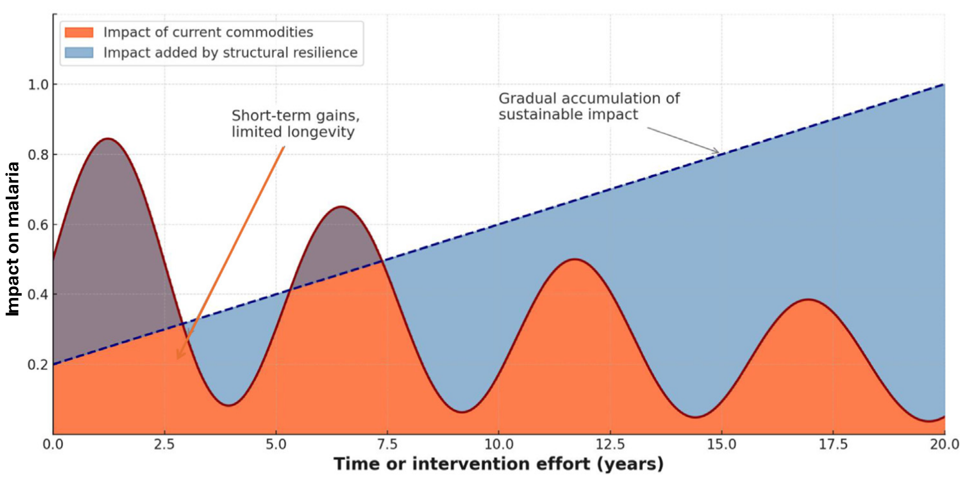

Figure 1. Conceptual illustration of the synergistic trajectory of malaria control when short-term commodities are paired with long-term structural resilience to safeguard and sustain malaria protection gains. The orange waveform represents the impact of current commodity-based tools (e.g., insecticide-treated nets, indoor residual spraying, seasonal chemoprevention), which produce rapid gains after each deployment but wane between cycles, leading to repeated peaks and troughs. The blue wedge shows the incremental impact added by structural resilience measures, such as improved housing, environmental management, and other durable interventions, which accumulate steadily over time. The navy broken line traces the combined effect, illustrating how gradual investments in resilience progressively elevate and stabilise overall control, transforming short-lived successes into a sustainable upward trend even as the performance of the commodities fluctuate periodically. Emerging transformative technologies, most notably self-propagating gene-drive mosquitoes, which are on the verge of being field-tested, and next-generation, long-lasting malaria vaccines, could add an extra upward lift to this trajectory, accelerating progress toward a 'sticky' state in which malaria transmission remains negligibly low without continuous external inputs.

Establishing the dual approach to safeguard malaria-control gains for the long term

Core recommendation 1. Countries should pursue an expanded version of species sanitation by prioritising the understanding and strategic suppression of the vector species responsible for most malaria infections

Species sanitation is key to achieving both immediate and sustained protection (Box 1). This approach was originally defined as a naturalistic means to vector control, directed against the main vectors through habitat modification in such a way that the vectors avoid these areas [7–9]. It

Box 1. Species sanitation: definition and historical examples

Species sanitation is a precision approach to malaria control first articulated in early 20th century Malaysia and Indonesia, after researchers realized that only a handful of local *Anopheles* species sustain transmission [12,68]. It is not a control method by itself, but rather a set of 'rationalistic' modifications of existing strategies to reduce the densities of target species below their effective transmission thresholds through selective measures adapted to their biology [11]. Instead of applying blanket measures, it fine-tunes existing tools to the ecology of the dominant vector. Although the term has traditionally denoted interventions targeting aquatic mosquito stages [11,12] it equally covers adult-stage control measures and is employed here in this broader sense. The process begins by ranking local anophelines based on their vectorial capacity and reproductive ecology; and it works best where the main vector species breed or rest in highly specific places that can be managed easily. This requires a detailed understanding of the taxonomy of local anophelines, their biting and resting behaviours, their preference for human blood, their ability to transmit malaria, longevity, dispersal capability, and perhaps most importantly, their choice of breeding site(s). Multiple highly successful historical examples of species sanitation exist, mostly from Asia [7,68] but also from Africa [69,70].

Batavia (now Jakarta) provides a classic case (Figure I). By 1917, malaria was rampant across the town, and spleen indices were highest along the coastline (Figure IA; red showing the percentage of children with enlarged spleens). Larval habitat surveys revealed the presence of ten anopheline species, the most abundant of which were *An. sundaicus* and *An. subpictus* that were breeding in the coastal fishponds area (Figure IB; fishponds shown in green). These two species accounted for 60% of 15 168 larvae and 98% of 8779 adult mosquitoes collected, and dissections showed that *An. sundaicus* carried sporozoites four to ten times more frequently than *An. subpictus*. Up to 100 million larvae emerged nightly because floating green algae hid them from larvivorous fish. Adult mosquito surveys showed that *An. sundaicus* migrated from the fishponds up to 2 km inland (Figure IC), transmitting malaria there. The control program did not shut the ponds; instead, workers drained them, dried and killed the algae, then reflooded once submerged blue-green algae (still suitable fish food) dominated. This 'hygienic exploitation' preserved livelihoods, maintained protein production, and, by exposing larvae to fish, crashed numbers of the primary vector; by 1930 child spleen rates and malaria prevalence had fallen sharply city-wide (Figure ID; red bars, 1917, green bars, 1930).

A second example of species sanitation took place between 1915 and 1919 in the town of Sibolga on the west coast of Sumatra. Sibolga lies on a bay, at the mouth of a small river, and is surrounded by steep foothills. The river passes into a 900 m wide floodplain. By 1912, malaria mortality in the town had reached a staggering 8% and threatened the economic future of the then trade centre. Five anopheline species were found breeding between the floodplain and the surrounding hills, but it was a specific location in the tidal swamp close to local quarters where refuse from a coconut plantation was dumped that obstructed tidal wave action and was most prolific in the production of *An. sundaicus*. Spleen indices near this site reached 98%. *An. sundaicus* was therefore the primary vector and caused infections in people from surrounding areas visiting the town centre. Although it was planned to fill the tidal swamp and remove all breeding sites, at a huge cost, it showed that restoration of tidal movement (through waste removal) in a focused fashion brought down mosquito numbers and disease transmission, which resulted in an 80% reduction in malaria mortality and halving of the spleen index by 1919 [71].

The Cihea plain, west of Bandung (Java) presents a third example. Development of a large rice irrigation scheme between 1854 and 1894 to alleviate famine was successful initially, but over time more and more fields became uncultivated due to malaria. The spleen index in children reached 79% in 1912. Mosquito surveys in houses, ditches, and rice fields resulted in seven different anopheline species, with an overwhelming majority of *An. aconitus*, which primarily bred in inundated, non-cultivated, weed-overgrown rice fields. Four measures were taken: immediate drainage of fields after harvest, simultaneous planting of rice fields, cleaning of irrigation and drainage ditches, and distribution of quinine when malaria was intense. Interestingly, rice yields increased from ca. 3 tonnes/ha in 1915 to 5 tonnes/ha in 1930. The spleen index in the entire Cihea plain dropped from 90.7% in 1919 to 15.9% in 1931 [68,72].

The lessons from these examples are consistent: when a small number of habitat-faithful vectors drive transmission, modest environmental tweaks or structural changes focused on that niche can deliver outsized gains that are both affordable and easily maintained by local communities. Where it builds on existing livelihood activities, species sanitation can attract local engagement and long-term maintenance without heavy recurrent costs.

Glossary

Environmental management: modifying natural or built environments to reduce mosquito breeding and human–vector contact.

Gene-drive mosquitoes: genetically modified mosquitoes designed to spread desired traits that either suppress or eliminate vector populations.

Health system strengthening: improving healthcare delivery, including diagnosis, treatment, and surveillance, to support malaria control.

Housing improvements: structural changes to homes, for example, screening, roofing, and elevating, aimed at reducing mosquito entry and human exposure.

Larval source management (LSM): the control of mosquito populations by targeting their aquatic breeding sites, typically through habitat modification or larviciding.

Resistance-breaking insecticide-treated nets (ITNs): advanced bed nets combining pyrethroids with additional insecticides like chlorfenapyr or pyriproxyfen to kill mosquitoes that are resistant to conventional pyrethroid-only ITNs. Effective against indoor-resting vectors such as *Anopheles funestus* and *Anopheles gambiae* in high-resistance settings.

Species sanitation: a targeted malaria-control strategy that focuses on suppressing or eliminating the specific mosquito species responsible for transmission, based on their ecological traits. Although the term has traditionally referred to interventions targeting the aquatic stages of mosquitoes, we employ it here in a broader sense to encompass control measures aimed at both the aquatic and adult stages of the dominant vector species.

Structural resilience: long-term gradual improvements to physical environments – for example, improved housing, surface water management – that make communities less hospitable to malaria mosquito vectors.

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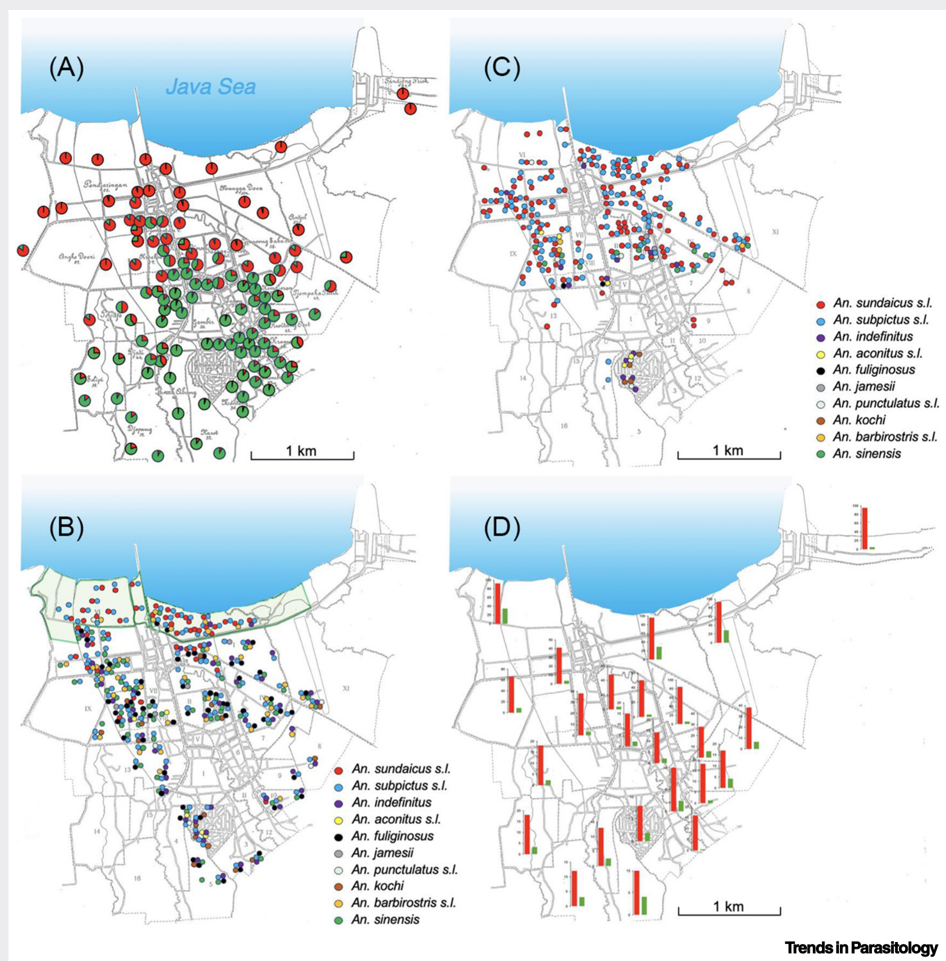

Figure I. Species sanitation in Jakarta, 1917–1930. Panel A maps the 1917 hotspot, shading the coastline red to mark the highest child spleen indices; Panel B highlights coastal fishponds in green, identifying them as prolific breeding sites for *An. sundaicus* and *An. subpictus*; Panel C traces arrows up to 2 km inland, showing *An. sundaicus* adults dispersing from the ponds and spreading malaria; Panel D compares red (1917) and green (1930) bars, documenting the sharp city-wide decline in child spleen rates after pond management cut vector numbers. Data source: [68].

requires detailed biological and ecological studies of local malaria vectors to accurately identify the primary species driving transmission and select interventions that effectively exploit the unique ecological and behavioural traits at different life stages of the mosquitoes [5,10]. The said interventions mostly targeted the aquatic stages, using concepts of environmental sanitation [11,12]. In its expanded form, which we propose here, the strategy would include exploiting unique ecological and behavioral traits of targeted mosquitoes in both their aquatic and adult stages. Where only a small number of *Anopheles* species are responsible for the majority of malaria transmission, combining targeted **larval source management** (**LSM**), house improvement and focused adulticiding can effectively collapse the populations of the dominant vectors, and disrupt malaria locally (Table 1). This would be especially practical if the target species breed in nonubiquitous, easily identifiable and accessible aquatic habitats, and primarily bite and rest inside houses [5,13]. Historically, broad-spectrum adult-targeting measures like DDT were viewed as adjuncts or alternatives to species sanitation, not part of it [11]. We contend, however, that

Table 1. Mosquito species and the relevance of species sanitation for malaria control in Africa, Asia and the Americas

Mosquito species (global)	>3600		
Anopheles species (global)	~460		
	Africa	Asia-Pacific	Americas
Anopheles species (regional)	~140	~200	~180
Malaria competence[a]	50–60	70–80	40–50
Secondary vectors[b]	40–45	50–55	30–35
Primary vectors[c]	10–15	20–25	10–15
Major vectors[d]	4	9	5
Species sanitation suitability[e]	1–3?	3?	2?
Examples of *Anopheles* species targetable by species sanitation at either adult and larvae stages, or mostly as adults[f]	*An. funestus, An. gambiae s.s., An. coluzzii*	*An. sundaicus, An. umbrosus, An. aconitus*	*An. darlingi, An. albimanus*

[a]Species known to transmit malaria in the field or under laboratory conditions.
[b]Species that are less broadly distributed, or that transmit only under specific ecological conditions or when primary vectors are scarce.
[c]Species that are important malaria vectors, either locally or regionally.
[d]Species that are broadly distributed and play a major role in malaria transmission.
[e]Species that have been – or may be – suitable for species-sanitation measures because of their ecology.
[f]While some species, such as *An. gambiae* s.s, may occupy small, rain-dependent and widely dispersed habitats that can be logistically difficult to target with larviciding in rural areas, their adult behaviours, being markedly endophilic (indoor-resting), anthropophilic (strong human host preference), and endophagic (indoor-feeding), make them readily controllable using indoor insecticidal interventions like ITNs and IRS or improved housing to prevent entry. Furthermore, both *An. coluzzii* and *An. gambiae s.s* remain significantly vulnerable to environmental management strategies that prevent the formation of their breeding habitats.

targeted adult-stage interventions, including not just house improvement measures like eave screening, but also modern insecticide-based measures, like ITNs and focal IRS, can address specific biting or resting behaviors of dominant vectors, aligning with Soper's definition of 'selectively reducing species densities below transmission thresholds based on their biology' [11]. Our concept of 'species sanitation' is therefore broader.

For instance, in many parts of Eastern and Southern Africa, *Anopheles funestus*, even when outnumbered by other vector species like *An. arabiensis*, is the principal malaria vector, responsible for >80% of transmission in some areas [14]. In many settings, this species is associated with relatively stable aquatic habitats, such as large ponds and slow-moving streams [15], which, though not universally identifiable, can, under the right ecological and operational conditions, be more consistently mapped and treated than the more diffuse, often transient, habitats of other vector species such as *An. arabiensis* [16,17]. Additionally, in several settings, adult *An. funestus* populations continue to be predominantly endophilic (indoor-resting), anthropophilic (prefers humans over other vertebrate blood hosts), and endophagic (indoor-feeding) [18,19], though some evidence points to behavioural plasticity by the species [20,21]. Other species such as *An. gambiae* s.s, occupy small, rain-dependent temporary habitats that are widely dispersed [16], and may be logistically less targetable with larviciding in rural areas though still susceptible to other forms of LSM such as habitat removal and manipulation. Another major vector species, *An. coluzzii*, is associated with longer-lasting, human-modified breeding sites, such as irrigated rice fields, reservoirs, drainage ditches, and, in some regions, urban pools that may be polluted [22]. In both cases, their adult behaviours are broadly similar to that of *An. funestus*, making them readily controllable using indoor insecticidal interventions or improved housing to prevent entry. Indeed, across East Africa, there are instances where *An. gambiae* s.s. populations were either eliminated or highly suppressed at local levels, following widescale deployment of **resistance-breaking insecticide-treated nets (ITNs)** [23,24]. These traits render such vector species particularly vulnerable to integrated interventions that include strategic adulticiding through high-quality indoor residual spraying (IRS), ITNs, or other insecticide-delivery formats such as at the eave spaces [25,26], coupled with targeted removal, manipulation or treatment of aquatic habitats of the dominant vector species.

Coordinating these larval and adult-stage interventions can sharply reduce local vector populations and effectively interrupt malaria transmission, but choosing the optimal tools requires rigorous, site-specific entomological and parasitological data. Indeed, some of the best documented cases of successful suppression, or even local extirpation, of *Anopheles* species in Africa have involved the use of IRS, sometimes implemented in combination with LSM [27]. Even when insecticide resistance emerges, switching to newer insecticide classes for IRS, or ITNs designed to overcome pyrethroid resistance can, in the short term, restore effective control [28,29]. In one study in northwestern Tanzania, dual-active ITNs containing pyrethroids and chlorfenapyr were highly effective against indoor feeding and resting *An. funestus* and associated malaria transmission [28,29]. Unfortunately, insecticide options for ITNs remain limited, largely confined to this single novel class, and piperonyl butoxide (PBO) nets have shown inconsistent efficacy, with recent evidence suggesting limited benefit in suppressing resistance selection in *An. funestus* [30]. By contrast, at least five chemical classes are now available for IRS, though their higher costs and logistical demands constrain widespread use. Nevertheless, other more potent resistance-breaking ITNs are already becoming available, which might enhance these effects [31], and where feasible, IRS can complement ITNs to suppress resistant vector populations.

Core recommendation 2. Countries should gradually build a layer of structural resilience in endemic communities to 'permanetize' the gains made from the commodity-driven approaches

No matter how effective IRS, ITNs, or larvicides are, they must be repeated or replaced regularly, requiring perpetual financing and coordination. Deliberately building layers of structural resilience to complement these programmes can offer the ultimate long-term strategy against malaria transmission, making households and communities inherently less conducive to mosquito proliferation and biting (Figure 1). While specific approaches to fostering resilience will vary between contexts, key strategies should include gradual and incremental improvements in housing quality and environmental conditions, with an initial prioritisation of the poorest households and communities. Even modest enhancements to homes and surroundings, such as those observed in small emergent towns in Africa, can lead to dramatic reductions in malaria transmission [32,33].

Malaria endemicity is intertwined with socioeconomic, infrastructural, and environmental factors that shape the vulnerability in communities [34,35]. Epidemiological studies, including randomised controlled trials, have demonstrated the effectiveness of specific housing interventions, such as screening windows and doors [36], in reducing malaria risk. However, these trials often fail to capture the full impact of combined infrastructural improvements, such as screening eaves, replacing thatched roofs with metal ones, or elevating homes in low-lying areas, all of which have individually been shown to reduce exposure to malaria [37,38].

Notably, **housing improvement** measures are often criticized as costly and difficult to scale up, which has hindered their adoption as mainstream interventions [39]. Nevertheless, the upgrades can be embedded into broader development plans, prioritising resource-deprived, high-burden areas. While the poorest households may require entirely new homes, most families could benefit from incremental, cost-effective measures such as subsidised screening of doors and windows, closing eaves, or installing metal roofs. Studies show that even small improvements, primarily financed by individual household incomes over several years, can yield dramatic reductions in malaria transmission [32,33].

One useful framework to consider is the DELIVER mnemonic proposed by Lindsay *et al*. [40], which outlines practical, context-adaptable measures for reducing malaria risk: ensuring doors are screened, self-closing, and gap-free (D); closing or screening eave spaces (E); elevating houses, or sleeping areas, above ground, where feasible (L); using ITNs for nighttime protection (I); providing ventilation through large, screened windows (V); regularly managing the surrounding environment (E); and replacing thatched roofs with solid materials like metal (R). These improvements, while effective in reducing malaria transmission, also offer broader benefits, enhancing overall health, comfort, and structural durability. See Box 2 for an illustrative timeline of how such resilience-building efforts can be phased and scaled over multiple decades.

Supplementary recommendation. Countries should actively pursue transformative technologies that can simultaneously reduce disease burden and strengthen resilience in low-income settings

The ultimate goal of our proposed strategy is to achieve a form of 'stickiness' in malaria control, whereby transmission remains at negligibly low levels without significant or continuous external inputs. The dual strategy that we have proposed here constitutes a foundational plan for reducing human–vector contacts and making communities less hospitable to *Anopheles* mosquitoes. Additionally, we recognise the potential of some emerging transformative technologies, which could accelerate the attainment of, and further enhance long-term resilience, especially in poor settings [41–43].

Innovations such as genetically engineered **gene-drive mosquitoes** and next-generation, long-lasting malaria vaccines may, eventually, replicate or even surpass the effect achieved through housing and environmental improvements, and may therefore be particularly suited for driving resilience in low-income settings [41–43]. Gene drives offer a pathway to self-propagating vector suppression or replacement, while durable vaccines could establish lasting population-level immunity. The only caveat is that these technologies are still under development and some years from being field-ready. Neither of the existing vaccines provides long-term, high-efficacy protection [44,45], and gene-drive systems require further testing, refinement, and regulatory approval before deployment at scale.

Although the necessary R&D investments might be substantial, these advancements offer the added benefit of eventually reducing the overall cost of malaria control [46,47], thereby disproportionately benefiting socioeconomically disadvantaged populations. Already, the ongoing

Box 2. Example of a multidecade plan for malaria vector control

This is an example of how a more realistic, multidecade malaria-prevention plan with overlapping phases could unfold, balancing immediate action with long-term resilience. In the near term (1–5 years), while immediate commodity-based interventions such as ITNs and IRS are the most crucial for rapidly reducing transmission, it is equally important to begin integrating resilience measures at this stage. Early initiatives should include modest housing improvements, initial community education programmes, and pilot projects in localised production of essential supplies. These measures are important to set the foundation for a more robust, self-reliant malaria-control system. As efforts progress into the medium term (3–15 years), resilience-building actions should be scaled up significantly. Investments in housing, such as designing and retrofitting low-income homes to reduce mosquito entry, should become more systematic, leveraging government subsidies and private sector financing as much as possible to complement the available house owners' expenditure on housing. Other efforts might include localised manufacturing of key supplies and intensified community engagement to further embed sustainable practices, helping countries to gradually reduce dependence on costly external inputs, mitigating the impact of rising commodity costs over time. In the long term (12–30 years), the focus should shift decisively toward establishing a resilient public health infrastructure. By this stage, strengthened health systems capable of rapid diagnosis and treatment, effective management of local water sources, and a well-established base of community-led initiatives will allow for a sustained reduction in malaria incidence. Commodity-based measures can be gradually phased out or maintained only for use in specific areas with residual high transmission and as a strategic reserve against potential outbreaks, ensuring that countries are not locked into expensive, short-term solutions.

adoption and scale-up of the current malaria vaccines by African countries could significantly reduce malaria-related deaths, helping to break the vicious cycle of disease and poverty.

Key considerations for achieving the dual approach

To achieve the dual approach, malaria programmes must fit seamlessly into people's livelihoods. Countries should combine community-driven, behaviour-centred interventions with skills training, incentives and supportive policies, while mobilising multisector partnerships and domestic financing. Sustained impact would then depend on coupling these locally tailored measures with robust health system strengthening in a way that complements the vector control strategies.

Incorporate human-centred programmes and policies for sustained malaria control

Sustained uptake of malaria interventions depends on how well they fit people's daily lives, preferences, and environments [48,49]. Housing improvements, for example, must not only be effective at preventing mosquito entry but also comfortable, functional, culturally appropriate and visually appealing. Similarly, effective **environmental management** should begin with understanding how local communities depend on the existing water sources, be they for crops, livestock, brickmaking, or mining, and then co-developing solutions that support, rather than disrupt, community livelihoods [50]. Since many mosquito habitats serve other essential purposes in communities, habitat management must be context sensitive [50]. For example, in areas where full removal is not feasible, combining larviciding with modified land use can significantly reduce vector populations while preserving critical resources.

Secondly, species sanitation is most effective when communities are actively engaged, especially through the employment of local labour, and well informed about the efforts. Technologies such as mobile apps, GIS mapping, and drone imagery can enhance surveillance, but should be deployed to support, not replace, community-led efforts or labour [51,52]. Public health education can provide a foundation for long-term behaviour change. It should strengthen understanding of vector-borne disease ecology and promote key protective behaviours, such as ITN use, eliminating standing water, mosquito-proofing homes, and seeking prompt care for fever. Teachers, youth leaders, health workers, and students can serve as trusted messengers and champions. Integrating mosquito-borne disease prevention into school curricula can help to foster a generation with the knowledge and commitment to sustain malaria control. Additionally, involving residents in activities such as mapping and prioritising aquatic habitats for LSM, spraying homes or conducting vector surveillance will ensure that the people are well-informed and engaged; and also that the interventions are socially acceptable.

Beyond education, governments should also emphasise removal of individual, social, and structural barriers that hinder improvements in health and development. This may include: (i) building skills, for example, training local contractors to construct safe and improved housing or training residents in environmental management; (ii) lowering costs – for example, by ensuring that affordable, high-quality building materials and designs are within reach – and applying behavioural insights to better understand how people make decisions and, in turn, design more effective policies, products, and services [53]. A recent meta-analysis found that structural interventions are often the most effective behavioural levers yet remain underutilised [54]. Other incentives, such as youth stipends for environmental work in their communities, subsidies for screens and roofing, and low-interest loans for community groups and households [55], can help to turn protective practices into lasting community norms.

Build multisectoral partnerships and expand financing options for malaria control

To date, a significant share of malaria funding in Africa has come from external donors, including the Global Fund to Fight HIV, Tuberculosis and Malaria, the US President's Malaria Initiative (PMI), and the Global Alliance for Vaccines and Immunization (GAVI), a global public–private partnership aimed at expanding immunization access in low-income countries[ii]. As of 2024, the Global Fund alone, primarily financed by Western nations such as the USA, the UK, and France, accounted for 62% of all international funding for malaria programmes and had invested over US$19.1 billion in malaria control by mid-2024. While these partnerships have led to major reductions in malaria burden, they are not sustainable, as donor priorities can change with shifting geopolitical priorities, emerging global crises, and competing domestic needs.

The recent suspension of US foreign aid, including reduced support for PMI initiatives, underscores how vulnerable public health programmes are to external political decisions [56]. Furthermore, reliance on external funding has, in some cases, reinforced siloed, commodity-driven approaches that prioritise clear, measurable outcomes, making it difficult to invest in integrated, longer-term solutions rooted in local systems and environments. Ultimately, long-term malaria control and elimination will require countries to pursue self-reliant, context-specific solutions to safeguard and advance the gains achieved through international support.

A promising route to sustainability is domestic resource mobilisation. Governments might allocate dedicated budgets to gradually build structural resilience against malaria and other vector-borne diseases while exploring alternative financing models to reduce reliance on external aid. For best results, domestic financing for disease control can be sequenced across time horizons: in the short term, governments can impose 'sin' taxes on alcohol and tobacco, add voluntary or mandatory health surcharges to tourism visas and airline tickets, and mobilise crowdfunding; in the medium term, they can issue diaspora bonds, solicit philanthropic donations, and forge public–private partnerships; and in the long term, they can establish nationwide health-insurance schemes and secure ring-fenced allocations within the regular government budget.

An especially vital component is the engagement of the private sector. As large industries benefit from a healthier workforce, corporate social responsibility programs naturally align with malaria control initiatives. Encouragingly, private sector investment in local manufacturing of malaria control tools is gaining momentum. For example, Vestergaard has announced the establishment of an ITN factory in Nigeria[iii], and S.C. Johnson has begun producing spatial repellents in Kenya[iv]. Earlier initiatives such as the Olyset Net factory in Tanzania, a partnership between Sumitomo Chemical and A to Z Textile Mills, further demonstrate this potential. Adopting these pathways can further reduce dependence on external suppliers and provide more purchasing options for consumers beyond the mass-distributed, foreign-funded products. However, challenges such as high production costs, limited infrastructure, complex regulatory frameworks, and restricted access to finance continue to constrain broader manufacturing expansion. Overcoming these barriers will be critical for unlocking the full potential of local production and building resilient malaria control systems.

The final critical aspect of essential partnerships is intersectoral collaboration within countries. By coordinating efforts across relevant ministries or departments (e.g., health, finance, agriculture, housing, environment, justice, and education), governments can integrate malaria control into broader socioeconomic development plans, addressing these interlinked challenges both sustainably and comprehensively. Moreover, as countries grapple with the looming impacts of climate change and extreme weather events, new opportunities are emerging to integrate malaria control efforts into the climate agenda as part of mitigation strategies to reduce potential negative impacts of such events [57,58].

Vector control stakeholders should acknowledge the importance of effective case management and broadly contribute to stronger health systems

A frequently overlooked but vital component of malaria prevention is the integration of vector control programs with robust health system improvements. Since Bhatt *et al.* estimated that nearly 80% of malaria reductions between 2000 and 2015 were linked to vector control measures (ITNs and IRS) [59], some have concluded, erroneously, that ITNs are a 'silver bullet' for malaria control and elimination; and that they are comparatively better than other interventions such as effective case management. Yet even Bhatt *et al.* acknowledged that the apparent disproportionate impact of ITNs arose from significantly greater investment in vector control relative to other interventions, such as effective diagnosis and treatment, and that their findings did not imply the inherent superiority of vector control [59].

Meanwhile, the latest World Malaria Report [1] highlights a more nuanced picture: while malaria deaths have steadily declined, the total number of cases continues to rise, suggesting that treatment and case management are improving, but preventive measures are not. These decoupled trends underscore the urgent need to reassess current prevention strategies and elevate the role of **health system strengthening** as a central pillar of malaria control. Importantly, effective vector control must be complemented by robust health systems capable of delivering consistent access to accurate diagnostics, effective antimalarial therapies, and trained health workers, especially in underserved rural areas where vulnerability is highest. As transmission declines, health systems take on an even more critical role in providing the surveillance and response infrastructure necessary to prevent isolated cases from triggering larger outbreaks. Over time, such systemic improvements will be essential for driving sustained reductions in both malaria incidence and mortality, laying a foundation for long-term control and eventual elimination.

Long-term strategic planning as a foundational first step

Countries should adopt longer-term strategic plans and integrate malaria control into a broader public health landscape rather than treating the disease in isolation

Most malaria strategic plans in Africa operate on 5-year cycles, even when the ultimate objective is nationwide elimination of the disease. According to the latest WHO estimates, interventions guided by these plans have prevented over 2 billion malaria cases and averted nearly 13 million deaths since 2000 [1]. Despite these remarkable achievements, many programmes cannot sustain their progress and are failing to reduce malaria below the threshold of a major public health concern. This is partly due to a growing strain on supply chains for essential commodities such as nets, insecticides, antimalarial drugs, and diagnostics, driven by population growth and rising costs [48]. In addition to inflationary pressures, newer tools and formulations developed to address biological threats – such as insecticide and drug resistance or failing diagnostics – are inherently more expensive [60]. Furthermore, many malaria programmes rely heavily on international donor funding earmarked for specific, time-limited objectives, often resulting in externally driven priorities that may not align with local needs [61,62]. In many endemic areas, communities simultaneously face other urgent health challenges, food insecurity, and fragile healthcare systems. As a result, a narrowly focused, time-bound approach to malaria control often struggles to gain lasting local support unless they are heavily subsidised.

Bed nets, insecticides, antimalarial drugs, and diagnostics are essential tools for immediate malaria control and can help to 'buy time' by rapidly reducing the disease burden. However, without addressing the underlying structural and environmental drivers of transmission, malaria is likely to persist, or resurge, once funding declines or biological threats, such as insecticide and drug resistance, intensify. By contrast, long-term investments in resilience-building measures are critical for sustained progress. Although these approaches may yield slower, less immediately visible results, they are foundational for long-lasting protection and resistance to future outbreaks. This perspective recognises that reducing malaria to manageable levels or achieving elimination is a generational effort, unlikely to succeed within the scope of short-term strategic plans spanning fewer than 10 years.

While the short-term gains are valuable, failing to invest in durable systems risks trapping countries in a costly cycle of externally driven interventions that are highly vulnerable to shifts in donor funding and the rising costs of essential commodities – challenges exemplified by recent disruptions in US foreign assistance, including funding cuts to the PMI. Box 2 presents a proposed multiphase roadmap for countries to transition from short-term commodity cycles to durable, self-reliant control systems over 30 years.

Malaria elimination is a laudable goal, but should be pursued only once local systems are robust enough to secure and maintain the gains already achieved

A related concern is that the global health policy rhetoric often champions the goal of malaria elimination, and even malaria eradication in some instances [63,64]. Emphasising the elimination of malaria in contexts where the burden remains high may spread resources too thinly and risk community and donor fatigue, especially if early gains are not solidly anchored in local capacity. Instead, the logical, more realistic objective is to first reduce case numbers to manageable levels in a sustainable manner. Once the disease burden is consistently low and health systems are robust enough to identify and respond to each new infection, the more ambitious vision of complete elimination can follow. Lessons can be drawn from China's '1-3-7' malaria strategy, where malaria cases were reported within 1 day, investigated and confirmed within 3 days, and appropriate public health responses implemented within 7 days to halt further transmission, eventually leading to malaria-free certification in 2021 [65–67]. This stepwise approach acknowledges that even partial progress of lower incidence, fewer deaths, and more targeted surveillance can yield significant health and economic benefits without overpromising short-term elimination or eradication in places with no ability to sustain 'zero malaria'. Critically, it also ensures that any progress made is durable, preventing the too-frequent boom-and-bust cycles in malaria control that occur when interventions are heavily reliant on external funding or short-lived programmes. In this way, countries can lay the groundwork for a future in which elimination is not just an aspirational tagline but a genuine, locally led possibility, with built-in resilience to keep the countries disease-free. Ultimately, although malaria elimination is a laudable goal, it should be pursued only once local systems are robust enough to secure and maintain the gains already achieved. Until then, the immediate priority for most countries should be reversing the current upward trends in cases, a goal that requires balancing targeted vector control with building structural resilience in communities.

Concluding remarks

Malaria control requires both immediate action and sustained, long-term strategies. While malaria-related deaths have declined, the persistently high case numbers in Africa reveal the limitations of current prevention efforts, which rely heavily on commodity-based tools like ITNs. This paper advocates for a more sustainable, phased approach, focusing on two overlapping components. First, countries should implement species sanitation by exploiting the ecology of primary *Anopheles* vector species to aggressively target both aquatic and adult stages using interventions such as LSM, IRS, and next-generation ITNs. Second, structural resilience must be built gradually through improvements in housing and environmental sanitation, making communities less hospitable to mosquitoes. Future innovations, like gene-drive mosquitoes and longer-lasting vaccines, could further amplify impact and enhance resilience in poor communities. These efforts must be underpinned by human-centred programmes and policies, multisectoral partnerships and domestic financing, and strong public health systems capable of promptly detecting and treating infections. We argue that this integrated approach, combining technical

Outstanding questions

Species sanitation

What are the best approaches for integrating ecological mapping and local knowledge to prioritise habitats for species sanitation interventions?

How can vector surveillance systems be optimised to support broader application of species sanitation?

What governance models best support multisector collaboration for integrated vector management?

Structural resilience

What are the long-term impacts of structural resilience measures on malaria incidence across different transmission settings?

What scalable financing models can support incremental home improvements among low-income households? How might these differ across countries?

How can domestic private sector actors be incentivized to produce and co-finance resilient housing materials?

Human-centred programmes and policies

What social and behavioural interventions are most effective in increasing uptake of incremental housing and environment improvements across contexts?

What role can school-based health education and youth-led campaigns play in sustaining protective malaria behaviours?

Long-term strategic planning

What factors might enable malaria programmes to transition to longer-term, integrated strategic planning?

What political and institutional factors influence domestic financing for malaria?

What are the long-term costs of implementing the dual approach compared to the current commodity-driven approach? How does this vary across contexts?

vector control with long-term systemic and community-driven investments, can offer both immediate impact and lasting protection. Malaria elimination should remain an aspirational but achievable goal, pursued through long-term planning and carefully sequenced efforts that enable local systems to detect and manage every case, ultimately breaking the cycle of resurgence.

There are a number of questions that can be further explored to effectively operationalise this approach across contexts (see Outstanding questions). These include how to identify and prioritise ecological targets for species sanitation using both surveillance data and local knowledge, and how to strengthen governance for multisector collaboration. Countries will also need to explore sustainable models for financing and implementing structural resilience, particularly among low-income households, and consider how to engage domestic industries in the production of resilient housing materials. Social and behaviour change approaches, co-designed with communities, should be evaluated to determine which interventions most effectively drive and sustain the adoption of housing and environmental improvements across diverse settings. Finally, countries must examine how to transition from short-term to long-term strategic planning, assess the political will and institutional capacity for domestic financing, and ensure health systems are equipped to maintain gains with reduced reliance on external support. These questions point to the need not only for deeper country-level inquiry but also for the development of a flexible framework, drawing on the recommendations provided here. This could help to guide implementation, support prioritisation, coordination, and long-term planning tailored to diverse national contexts. Answering these questions and applying the insights they generate will be critical for translating this vision into practice.

How might strategies be tailored to account for unique social, economic, and political factors across countries?

What surveillance and health system capacities are needed to sustain low transmission in the absence of external support?

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Declaration of interests

The authors declare no competing interests.

Resources

[i]https://donortracker.org/

[ii]www.theglobalfund.org/en/malaria/

[iii]https://vestergaard.com/

[iv]www.scjohnson.com/

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