Designing National Government Systems to Integrate Malaria Early Warning Systems With Precision

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Introduction

Malaria remains one of the most pressing global health challenges, with an estimated 282 million cases and 610,000 deaths worldwide in 2024 (WHO, 2025). Sub-Saharan Africa bears the greatest burden of this disease. Despite major progress in malaria eradication, gaps in coverage of interventions coupled with the ineffective targeting of programs continue to undermine international elimination efforts. Interventions such as insecticide-treated nets (ITNs), indoor spraying, and vaccines helping to reduce the incidence of malaria to a great extent. Estimates suggest that between 2000 and 2015, the scale-up of interventions like ITNs, indoor residual spraying, and vaccines contributed to the reducing the global death rate for malaria by half. Mortality rates have declined by another 7.4% over the last 9 years (WHO, 2025). However, funding shortfalls and uneven progress highlight the need for smarter, more adaptive tools to guide the allocation of resources to prevent malaria. Malaria early warning systems (EWS) could contribute to this objective.

To make EWS effective and sustainable, researchers must go beyond technical precision and meet the following three principles, which are critical:

AIR's Data Exploration Hub

The Data Exploration Hub is a dynamic, centralized platform to support AIR and our partners in leveraging diverse datasets for research, policy analysis, and operational needs. Its architecture is built to serve as a one-stop shop for project data, ensuring consistency, reliability, and comprehensive management. The Data Exploration Hub ingests and transforms historical and new datasets, making them analysis-ready and accessible for a wide range of users. The platform streamlines cross-domain data integration, enabling users to combine datasets from various sources to answer complex research questions and support evidence-based decision making.

1. **Co-create EWS models with governments** to ensure ownership, integration into national health systems, and long-term sustainability beyond donor funding.
2. **Combine malaria domain knowledge with advanced modeling expertise** to ensure that projections are precise and operationally actionable.
3. **Use co-creation as a foundation for building systems and capacity,** enabling governments to maintain and update models independently and strengthen decision-making processes.

These principles are essential for maximizing the impact and cost-effectiveness of investments and for ensuring that EWSs deliver timely, actionable insights where they are needed most.

Next Steps for the Field

The field of malaria modeling is at a crossroads. Although predictive tools have advanced significantly, most of the current approaches are still fragmented and disconnected from the realities of national health systems. To deliver real-world impact, malaria EWS must evolve to become practical decision-support tools that governments can own, adapt, and sustain. This will require a shift toward co-created models that integrate malaria domain expertise with advanced analytics, prioritize usability for diverse contexts, and embed capacity building as a core design principle. Without this shift, even the most sophisticated EWS models risk becoming underused and failing to influence resource allocation where it matters most.

EWS have proven their value in other domains, such as food security and famines (e.g., see FEWS NET for which the American Institutes for Research® [AIR®] manages the Data, Learning, and Communications Hub), extreme weather, and political violence. They have done so by identifying high-risk areas and enabling timely interventions. A malaria EWS could conceivably do the same: anticipate outbreaks, guide resource allocation, and help governments and funders maximize the impact of their limited budgets.

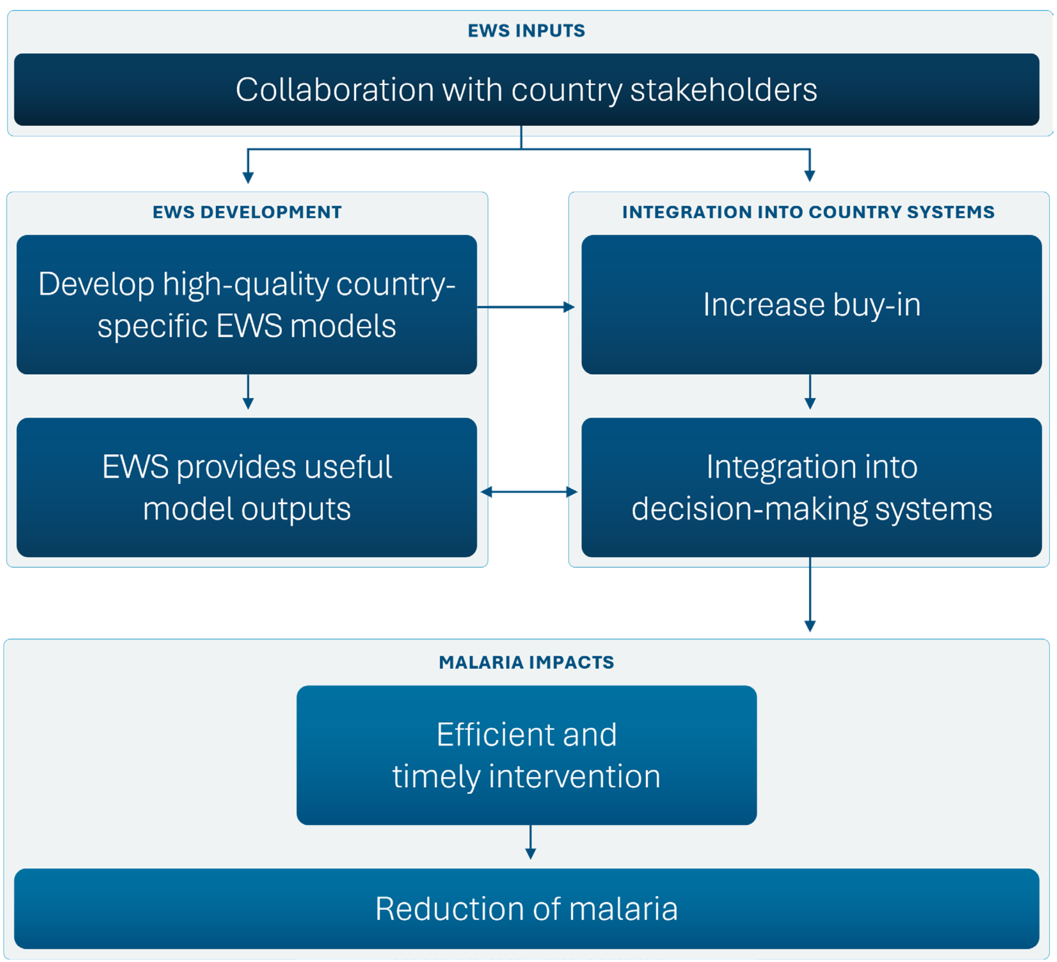
However, researchers face persistent challenges in balancing three critical factors (Mategula et al., 2025):

- **Precision.** This refers to the accuracy of risk estimates and forecasts.
- **Usability.** This refers to the ability of such systems to generate actionable insights that are understandable and timely.
- **Adaptability.** This refers to the need for flexible models that can adapt across diverse contexts and changing conditions.

Models must achieve high predictive accuracy while remaining practical for routine use by national governments with varying capacities and resource constraints. Overly complex models may offer marginal precision gains but become inaccessible for decision makers. Conversely, overly simplified models may lead to misallocation of resources.

Researchers should also account for country-specific contexts. For example, seasonal malaria chemoprevention may be highly effective in the Sahel but it is less relevant in the highlands of Kenya. These differences underscore the need for models that integrate local data and allow for rapid updates as conditions shift, whether due to climate shocks, conflict, or changes in intervention effectiveness.

Ultimately, the next phase of malaria EWS development should prioritize co-creation with governments, integration of **malaria expertise with advanced modeling**, and **capacity building for sustainability**. By embedding these principles, researchers can move beyond technical innovation toward systems that deliver actionable, country-specific insights and strengthen national decision making for years to come.



Optimizing the Precision of Malaria Models

Malaria transmission is shaped by environmental, biological, and human factors, making predictive modeling a complex exercise. Models range from purely data-driven approaches to those that are based on theoretical relationships. Advances in artificial intelligence (AI) and geospatial analytics enable the integration of diverse data sets and iterative learning, improving accuracy and adaptability. However, technical sophistication alone is insufficient. Domain knowledge about mosquito behavior, parasite life cycles, and human immunity remains critical.

For example, climatic changes such as shifts in rainfall and temperature alter mosquito breeding patterns and malaria transmission risk. Biological factors determine how efficiently malaria spreads, while human factors (e.g., mobility, immunity, health care access) affect exposure and treatment-seeking behavior. High population immunity may reduce treatment-seeking behavior, allowing parasite reservoirs to persist and increasing risk among young children. These dynamics underscore the need for hybrid models that combine machine learning with epidemiological expertise.

Precision must also reflect country-specific contexts. Global models often misestimate incidence because intervention effects are nonlinear, and starting conditions vary widely. In Kenya, where transmission is seasonal and concentrated in rural areas, ITNs can have large additional effects. In Chad, where transmission is perennial and resistance is widespread, the same intervention may yield smaller gains. This example highlights why models should incorporate local data and allow for rapid updates as conditions change.

Maximizing the Sustainability of a Malaria EWS

Creating sustainable WS requires systems that governments can maintain and adapt over time. Contextual factors such as conflict, climate shocks, and health system disruptions can dramatically alter risk patterns. Models must therefore include parameters that predict the effects of changes in these factors over time, projecting future risk while integrating current incidence and intervention coverage.

Co-creation with governments is central to sustainability. Joint development ensures that models reflect local realities, build ownership, and strengthen institutional capacity. This includes training national teams to interpret outputs, update models, and integrate EWS into routine decision making. Country-specific models also allow for the development of meaningful indicators, such as prioritizing the high risk of malaria incidence among children under age 5 in areas with high general immunity.

Finally, usability matters. Governments need tools that not only identify where risk is high but also suggest actionable pathways. Emerging AI technologies can support this objective by synthesizing risk drivers, intervention evidence, and contextual factors into concise decision-support outputs. For example, AI-supported decision making can help countries move from simply understanding where risk is high to addressing the risk. Countries can use information on identified risk factors, empirical evidence on intervention impacts, and contextual factors (e.g., media coverage, policy documents) to generate summary reports outlining potential action pathways. With tightening health budgets, tools that can combine precision with practical guidance will be essential for efficient resource allocation.

Conclusion

Malaria EWS can transform how resources are allocated and how risks are managed. However, this requires that these systems evolve into practical, sustainable tools. The next phase of development requires models that are co-created with governments, integrate malaria expertise with advanced analytics, and embed capacity building to ensure long-term use. Funders and policymakers play a critical role in enabling this shift by prioritizing investments that support collaboration, adaptability, and usability.

AIR is committed to advancing these principles by piloting co-created EWS in high-burden countries, combining malaria domain knowledge with cutting-edge modeling approaches, and building capacity within national health systems. By aligning research and funding with these priorities, the global health community can deliver tools that not only predict risk but also empower countries to act decisively. In this way, malaria prediction models and EWS can accelerate progress toward reducing the burden of malaria and saving lives.

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