Architecture of a Learning Surveillance System for Malaria Elimination in India

S D Sreeganga[1][a], Susanna G. Mitra[1][b] and Arkalgud Ramaprasad[1,2][c]
[1]*Ramaiah Public Policy Center, Bengaluru, India*
[2]*University of Illinois, Chicago, U.S.A.*

Keywords: Cyberenvironment, Learning System, Surveillance, Feedback-loop, Malaria Elimination.

Abstract: Surveillance is critical for malaria elimination. Malaria transmission takes place in a dynamic and complex environment. The key goal in developing a malaria surveillance system is to ensure that it is robust, systematic, and effective for improving data availability for decision-making. We present a unified framework for envisioning malaria surveillance informatics as an ontology-based feedback system. The framework presented is a solution for the current fragmented and linear surveillance processes for malaria case management. It encapsulates a comprehensive natural language enumeration of the requirements of the cyberenvironment, structured into 5 dimensions - timing, surveillance process, information surveyed, malaria management, and stakeholder, with each of them articulated as a taxonomy of its constituent elements. The elements are combined to form natural language statements of the cyberenvironment requirement. The information generation through the semiotic cycle provides real-time sense and response capability for timely and targeted interventions. The response mechanism creates both positively and negatively reinforcing feedback-based learning processes at multiple levels. Such a system enables data interoperability for capturing malaria incidence, discover epidemiological clusters, and predict propagation dynamics. On a larger scale, the integrative framework enables data harmonization, analytics, and visualization towards effective management and knowledge generation on disease surveillance.

1 INTRODUCTION

Malaria is a major global health problem, and a leading cause of disease and death across many tropical and subtropical countries. The World Malaria Report 2018 estimates that there were 219 million malaria cases, and 435 thousand related deaths in 2017 (World Health Organization, 2018). Global efforts to control malaria during 2000-2015 had resulted in substantial reductions in cases of malaria incidence and mortality rate (Cibulskis et al., 2016). However, the public health burden of the disease has continued through new manifestations of its source from Plasmodium Falciparum to P. Vivax, emergence of new transmission modes due to human mobility, and epidemiological shifts in the populations most at risk of malaria (Cotter et al., 2013). Adding to the burden are issues of low malaria testing rates and high numbers of unconfirmed malaria cases that need constant monitoring to sustain the reductions (McMorrow, Aidoo, & Kachur, 2011). These new circumstances have prompted shifts in global strategies from traditional control interventions to novel measures for completeness, timeliness of activities to seek out infections, and interrupt transmissions (Cotter et al., 2013).

Constant malaria monitoring and surveillance systems have been highlighted as critical and a core intervention strategy to achieve malaria elimination (The malERA Consultative Group on Monitoring, Evaluation, and Surveillance, 2011). Malaria surveillance in the current elimination phase is directed at stopping local transmission of malaria. It involves a dual strategy of a) identifying and determining areas with local transmission and its sources; and b) detecting the characteristics of

[a] https://orcid.org/0000-0001-7308-6851
[b] https://orcid.org/0000-0001-5784-5950
[c] https://orcid.org/0000-0003-1551-6854

Sreeganga, S., Mitra, S. and Ramaprasad, A.
Architecture of a Learning Surveillance System for Malaria Elimination in India.
DOI: 10.5220/0008944103770382
In *Proceedings of the 13th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2020) - Volume 5: HEALTHINF*, pages 377-382
ISBN: 978-989-758-398-8; ISSN: 2184-4305

transmission with intensified surveillance and appropriate control measures taken (Cibulskis, 2012). WHO 2018 report emphasizes that a strong surveillance system requires high levels of access to care and case detection, and complete reporting of health information by all sectors, whether public or private (World Hea Organization, 2018). This has led to a concerted global effort towards large-scale, robust surveillance mechanisms that measure rather than estimate the actual burden of malaria over time from large areas of the continent (Nkumama, O'Meara, & Osier, 2017). Aiding such efforts are technological advances in surveillance systems, including timeliness for rapid detection of local outbreaks (Chehab M. et al., 2018), interoperability for rapid data exchange between different platforms, (Brenas, Al-Manir, Baker, & Shaban-Nejad, 2017) and accessible data storage with management (UCSF Global Health Sciences, 2014).

However, the need to communicate this change in strategic thinking to large, cumbersome health systems has proven a challenge (Cao et al., 2014). Malaria represents complex and dynamic interactions among ecosystems, livelihoods, and health systems (Mboera, Mfinanga, Karimuribo, Rumisha, & Sindato, 2014). In case of malaria surveillance, there is a strong argument for designing data reservoir platforms that facilitate monitoring, learning and evaluation (MLE) among multiple actors to optimize coordinated, integrated disease detection, and intervention efforts (Barclay, Smith, & Findeis, 2012). Current surveillance systems remain predominantly linear and ineffective in tackling the complexities of malaria elimination. This is evident from a recent empirical study evaluating malaria surveillance in 16 countries during 2015-2017. It highlighted the main systemic gaps as lack of coverage in remote communities and inadequate health information architecture to capture high quality case-based data. Other shortcomings were partial integration of intervention information, poor visualization of generated information, and disjointed data for making programmatic decisions (Lourenço et al., 2019).

To bring in systematic and effective data generation, integration, and dissemination for malaria elimination, we argue for a Learning Surveillance System. This is in line with the Learning Health Systems described as 'cyber-social ecosystem', to solve complex interdisciplinary problems of timely evidence, and supporting best care practices (Lessard et al., 2019). It requires explicit conceptualization using tools that can be used to establish a communication protocol, describe information flows within a complex setting of malaria elimination, facilitate analysis, and design of a learning surveillance system. Our paper introduces a promising first step to help address this challenge by demonstrating how an ontological approach can facilitate analysis and design of a learning surveillance system for malaria.

2 ONTOLOGICAL FRAMEWORK

The ontology encapsulates a comprehensive natural language enumeration of the requirements of the cyberenvironment for malaria surveillance using a structured terminology that can be used to systematically analyze and prioritize the functions of the cyberenvironment (Brooks & Ramaprasad, 2008). It builds on an earlier work titled 'Ontology of a Cyberenvironment for Malaria Surveillance'(Brooks & Ramaprasad, 2008), by adding more elements to the framework to reflect the current complex and dynamic malaria landscape. Making use of this ontological framework one can move from the traditional linear surveillance system to a nonlinear responsive, and iterative surveillance system for malaria elimination programmes across the world.

The malaria surveillance ontological framework is shown in Figure 1. The object of the framework is to create an architecture of socio-cyberenvironment for a learning surveillance system for malaria elimination. The ontology comprises of five dimensions, with each being defined by a taxonomy of elements that constitute a learning surveillance system. The framework encapsulates pathways for the management of a malaria surveillance system. Each pathway is a concatenation of an element from the five columns, left to right, with the adjacent words/phrases.

Malaria surveillance is based on various types of data used for managing malaria by different stakeholders, as listed in third to fifth columns of the framework. The third column represents various types of surveillance data integral to malaria elimination. It includes data on mosquito species characteristics, their habitation, regional population demographics, case incidence rates which form the information base for health analytics (Merkord et al., 2017).

The fourth column from the left denotes malaria management that focuses on managing symptoms, causes, treatment, and prevention of malaria. This includes targeted interventions for malaria control through measures such as rapid diagnostic tests, insecticide treated mosquito nets, mosquito control,

Timing	[+]	Surveillance	[of]	Data	[data for]	Malaria Managemment	[by/for]	Stakeholder
Ad hoc		Identification		Entomological		Medical treatment		Healthcare Provider
Post hoc		Detection		Parasitological		Active malaria cases		People
On-demand		Collection		Demographic		Asymptomatic cases		Physician
Periodic		Analysis		Socio-economic		Prophylaxis		Nurse
Real-time		Interpretation		Clinical		Stock of drugs		Pharmacist
Predictive		Application		Epidemiological		Fake drugs		ASHA worker
		Reporting		Ecological		Drug resistance		Volunteer
		Feedback		Climate		Personal Protection		Entity
				Geographical		Insecticide treated bed nets		Hospital
				Financial		Interior residential spraying		Clinic
						Insecticide treated clothing		Pharmacy
						House design		Home
						Physical barriers		Citizen
						Mosquito (vector) control		Individual
						Mosquito source control		Family
						Adult mosquito control		Community
						Identification of new species		Agency
						Strategic management		Public
						Resource allocation		Private
						Training		NGO
						Outcome assessment		Academia

Figure 1: Ontology of a Cyberenvironment for Malaria Surveillance in India.

and strategic management (Dhamnetiya & Sahu, 2015; van Eijk et al., 2016). Effective surveillance of malaria cases and deaths is essential for identifying the areas or population groups that are most affected by malaria, and for targeting resources for maximum impact. The fifth column from the left provides the multitude of stakeholders including the healthcare sector, different external entities, and individuals engaged in malarial control ecosystem. Considering the columns of data, malaria management, and stakeholder along with each of its elements the framework forms a natural language sentence. Combining the three columns will create pathways from simple information service to complex interaction service. For example: clinical data for active malaria cases by a clinic; or, financial data for stock of drugs by a pharmacy.

The surveillance tools and strategies are themselves characterized by timing and stages, listed in the first two columns of the framework (from the left). The second column of the framework articulates the full scope of a surveillance system that allows sense and response, making it a learning surveillance system. Case identification, detection, and data collection are direct and cover both active and passive cases at health facilities, communities during investigation, and screening activities. A malaria elimination information system should include automated data analysis to ensure timely outputs, expert analysis for policy, and programming decisions. The data generated as output results will enable identification of threats such as outbreaks and inform responses. The impact of the response can be captured by the surveillance system and can inform further iterative changes to the interventions. Expert analysis of the data and its interpretation will impact different combinations of interventions. The whole cycle will automatically generate outputs tailored to the level of the health systems including visualizations of analyzed data, work task lists, reports for internal use, and by external organizations. A feedback system occurs on a real-time basis.

The first column represents the temporal dimension of the iterative process that increases the quality and reliability of the data. It can range from the ad-hoc through real-time to predictive. Thus, the learning surveillance system encapsulates both immediate, and predictive indicators for malaria elimination.

Tracing the ontology, the pathways of a malaria surveillance system read as:

- Real-time collection of clinical data for active malaria cases by ASHA worker.
- Predictive analysis of socio-economic data for mosquito vector control by private agency.
- On-demand feedback of epidemiological data for

strategic management by public agency.

3 DISCUSSION

The ontological framework described above provides the architecture of an integrated and consistent knowledge source for malaria elimination. Through its frame, one can collect, formalize, integrate, analyze, and manipulate all types of malaria-related data. The pathways formed capture the relationships between timing, surveillance, data, malaria management, and stakeholders of the malarial system.

Its usefulness as a comprehensive and readily searchable knowledge repository is evident, when applied to recent studies within the domain. For instance, the ontology clearly encapsulates the key focus areas for malaria surveillance, as emphasized by Barclay et al. (2012). The first urgent need for rapid detection of existing, new or re-introduced infections is clearly reflected by the ontological pathway of real-time/on-demand detection of parasitological, entomological, epidemiological, and demographic data. The authors also highlight the need for identification of periods of low transmission (e.g., from symptomatic and asymptomatic infections) when the parasite population could be most amenable to elimination as well as trends in malaria incidence, and prevalence in different age groups, increasing parasite heterogeneity, changes in seasonality. This complex phenomenon is indicated through the ontological pathways of identification, detection, and collection of data on asymptomatic cases and analysis of data collected on parasitological, demographic, and climate data respectively. Even their emphasis on the issue of detection of resistance currently central to malaria elimination is captured by ontological pathway of analysis of clinical data on drug resistance. Hence, the ontology, in conjunction with regular medical standards, can construct a semantically intelligent malaria decision-making system.

The ontology is also a useful domain link for the feedback loop in surveillance systems, which in recent years, has become essential to Learning Health Care Systems (Kass & Faden, 2018). The usefulness of the feedback model was evident in the enhanced malaria surveillance programme undertaken by the Zambian government that recorded success in Lusaka District within two years. It replaced intermittent population-based surveys with data generation from continuously operating health information systems. The learning from the feedback helped redesign the strategies for malaria elimination as it significantly reduced malaria reporting, and unnecessary anti-malarial treatment administration, especially in areas with variable malaria transmission patterns (Chisha et al., 2015).

The key difference between existing surveillance systems and the proposed one is the real-time learning capability through the feedback-loop. The iterative cycle inherent to the feedback-loop is transformed into an advanced learning model that can guide the system along the trajectory of malaria elimination. The timely feedback system will help recognize, amplify the effective actions for malaria elimination, and similarly attenuate the ineffective ones. The learning from the feedback will help redesign the strategies for malaria elimination. This learning capability can be deployed to develop: (a) positively reinforcing feedback cycles that amplify and accelerate the desirable outcomes, and (b) negatively reinforcing cycles that attenuate and decelerate undesirable outcomes. Further this combination of positively and negatively reinforcing feedback cycles will generate a desirable non-linear, positive impact on malaria elimination, that will not only verify trends in reported malaria, but also incorporate a data feedback loop to improve data uptake, use, and quality. The semiotic cycle will lead to predictive capability, responsiveness to occurrence, and propagation for pro-active management of malaria. It facilitates the development of predictive systems for malaria involving repeated updates on the initial conditions based on the new epidemiological data, and the inference method that naturally lends itself to this purpose, given its time-sequential application (Roy, Bouma, Dhiman, & Pascual, 2015). Such precision will help improve both the efficiency and effectiveness of the efforts to eliminate the disease. It will also help foster the sharing of knowledge generated and its application.

Malaria surveillance systems aim to assist public health practitioners and decision makers to (a) identify the regions or populations affected by malaria; (b) identify trends in malaria morbidity and mortality; and (c) evaluate preventive or therapeutic malaria interventions, and programs (Brenas et al., 2017). In combination with the latest technological advancements, the feedback process based on this ontological framework enables a multi-layered approach to malaria surveillance system. It involves a three-level feedback mechanism that creates a sense and response capability at different levels, to enable a quick feedback cycle facilitating a non-linear, iterative process for malaria elimination. For a rapid feedback on malaria occurrence, at the first level, the process involves a robust reporting system for different stakeholders, including doctors, patients, and care-providers. Epidemiological cluster data is a second level data-based process that will enable identifying malaria 'hotspots' including regional variation of high and low endemic areas. Propagation Dynamics is the third level of surveillance strategy for the prevention of transmission of malaria; it will focus on both temporal and spatial propagation of malaria. The transmission parameters themselves are also updated by refitting the model over a moving window of time. Application of these approaches enables the predictability of epidemic malaria at different levels.

The ontology is amenable to a multi-organizational setup inherent to malaria management. It creates an appropriate interface with community-based approaches, common in malaria management. The global evidence on malaria management suggests necessary preconditions to ensure the effectiveness of community-based approaches. For instance, there is an emphasis on community engagement at the inception and planning stage rather than being mere recipients (Whittaker & Smith, 2015). In the case of India, where ASHA (Accredited Social Health Activists) workers are engaged in management of the disease at the local level, there is a strong pitch for their empowerment. It has been pointed out that communities should be empowered to regularly monitor and evaluate the effectiveness of interventions. Such practices through institutions, and individuals further enhances the community's participation and ownership. (Das et al., 2015). The ontological framework for malaria surveillance complements such community-based approaches: it creates a learning driven process with a multi-layered feedback mechanism that facilitates a 'Sense and Response' system. In addition to detection, diagnosis, and monitoring of the cases, it will increase the speed by which regional and national surveillance teams are alerted to local events and prepare intervention services for local demands.

The near real-time technique provided by this framework can be implemented within the scope of existing infrastructure and human resources. It leverages the current accelerated internet and smartphone penetration across the world. Minimum training only is required for a user as it's easy to use. For instance, through cloud computing platform integrated with mobile apps, which facilitates access to data in the cloud through smartphones, feature phones, tablets and desktops is useful for various stakeholders at various skill levels (El-Sappagh, Ali, Hendawi, Jang, & Kwak, 2019; Quan, Hulth, Kok, & Blumberg, 2014). Therefore, this approach is relevant in the context of resource-constrained countries in parts of Asia, Africa, and Latin America, with already overburdened health systems.

4 CONCLUSIONS

This paper argues for a learning surveillance system for malaria elimination and presents the ontological framework to develop the system. It provides a detailed, yet holistic understanding of how semiotic interchanges will make the Learning Surveillance System vision a reality. The ontology has policy implications as governments around the world look to improving the efficiency, and outcomes of their surveillance organizations, and systems. Understanding how learning system ontology can support surveillance will contribute to funding planning, and policies. It highlights the gaps related to the type of digital technology currently leveraged for surveillance systems. Healthcare providers will find a supportive platform in this ontology as it is likely to change their practice in future.

ACKNOWLEDGEMENTS

We thank Dr Chetan Singai for his valuable insights on the paper.

REFERENCES

Barclay, V. C., Smith, R. A., & Findeis, J. L. (2012). Surveillance considerations for malaria elimination. *Malaria Journal*, *11*, 304. https://doi.org/10.1186/1475-2875-11-304

Brenas, J. H., Al-Manir, M. S., Baker, C. J. O., & Shaban-Nejad, A. (2017). A Malaria Analytics Framework to Support Evolution and Interoperability of Global Health Surveillance Systems. *IEEE Access*, *5*, 21605–21619. https://doi.org/10.1109/ACCESS.2017.2761232

Brooks, I., & Ramaprasad, A. (2008). Ontology of a Cyberenvironment for Malaria Surveillance. In *Advances in Disease Surveillance* (p. 5:8). Retrieved from http://www.ssrn.com/abstract=1325788

Cao, J., Sturrock, H. J. W., Cotter, C., Zhou, S., Zhou, H., Liu, Y., … Gao, Q. (2014). Communicating and Monitoring Surveillance and Response Activities for Malaria Elimination: China's "1-3-7" Strategy. *PLoS Medicine*, *11*(5), e1001642. https://doi.org/10.1371/journal.pmed.1001642

Chehab M., Bala, M. O., Al-Dahshan, A., Selim, N. A., Al-Romaihi, H. E., Al-Thani, M., & Farag, E. A. (2018). Evaluation of the Completeness and Timeliness of National Malaria Surveillance System in Qatar, 2016. *Cureus*, *10*(6). Retrieved from https://www.cureus.com/articles/10295-evaluation-of-the-completeness-and-timeliness-of-national-malaria-surveillance-system-in-qatar-2016

Chisha, Z., Larsen, D. A., Burns, M., Miller, J. M., Chirwa, J., Mbwili, C., … Winters, A. M. (2015). Enhanced surveillance and data feedback loop associated with improved malaria data in Lusaka, Zambia. *Malaria Journal*, *14*(1), 222. https://doi.org/10.1186/s12936-015-0735-y

Cibulskis, R. E. (2012). Malaria surveillance systems: From control to elimination. *Malaria Journal*, *11*(S1), O1. https://doi.org/10.1186/1475-2875-11-S1-O1

Cibulskis, R. E., Alonso, P., Aponte, J., Aregawi, M., Barrette, A., Bergeron, L., … Williams, R. (2016). Malaria: Global progress 2000 – 2015 and future challenges. *Infectious Diseases of Poverty*, *5*(1), 61, s40249-016-0151–0158. https://doi.org/10.1186/s40249-016-0151-8

Cotter, C., Sturrock, H. J. W., Hsiang, M. S., Liu, J., Phillips, A. A., Hwang, J., … Feachem, R. G. A. (2013). The changing epidemiology of malaria elimination: New strategies for new challenges. *Lancet (London, England)*, *382*(9895), 900–911. https://doi.org/10.1016/S0140-6736(13)60310-4

Das, A., Friedman, J., Kandpal, E., Ramana, G. N. V., Gupta, R. K. D., Pradhan, M. M., & Govindaraj, R. (2015). *Strengthening Malaria Service Delivery Through Supportive Supervision and Community Mobilization in an Endemic Indian Setting: An Evaluation of Nested Delivery Models*. 12.

Dhamnetiya, D., & Sahu, M. (2015). Malaria Control in India: Strategies, Progress and Challenges. *International Journal of Contemporary Medicine*, *3*(1), 14. https://doi.org/10.5958/2321-1032.2015.00005.4

El-Sappagh, S., Ali, F., Hendawi, A., Jang, J.-H., & Kwak, K.-S. (2019). A mobile health monitoring-and-treatment system based on integration of the SSN sensor ontology and the HL7 FHIR standard. *BMC Medical Informatics and Decision Making*, *19*(1), 97. https://doi.org/10.1186/s12911-019-0806-z

Kass, N. E., & Faden, R. R. (2018). Ethics and Learning Health Care: The Essential roles of engagement, transparency, and accountability. *Learning Health Systems*, *2*(4), e10066. https://doi.org/10.1002/lrh2.10066

Lessard, L., Grudniewicz, A., Sauré, A., Szczotka, A., King, J., & Fung-Kee-Fung, M. (2019). Type and use of digital technology in learning health systems: A scoping review protocol. *BMJ Open*, *9*(5), e026204. https://doi.org/10.1136/bmjopen-2018-026204

Lourenço, C., Tatem, A. J., Atkinson, P. M., Cohen, J. M., Pindolia, D., Bhavnani, D., & Le Menach, A. (2019). Strengthening surveillance systems for malaria elimination: A global landscaping of system performance, 2015–2017. *Malaria Journal*, *18*(1), 315. https://doi.org/10.1186/s12936-019-2960-2

Mboera, L. E. G., Mfinanga, S. G., Karimuribo, E. D., Rumisha, S. F., & Sindato, C. (2014). The changing landscape of public health in sub-Saharan Africa: Control and prevention of communicable diseases needs rethinking. *Onderstepoort Journal of Veterinary Research*, *81*(2), 6. https://doi.org/10.4102/ojvr.v81i2.734

McMorrow, M. L., Aidoo, M., & Kachur, S. P. (2011). Malaria rapid diagnostic tests in elimination settings—Can they find the last parasite? *Clinical Microbiology and Infection*, *17*(11), 1624–1631. https://doi.org/10.1111/j.1469-0691.2011.03639.x

Merkord, C. L., Liu, Y., Mihretie, A., Gebrehiwot, T., Awoke, W., Bayabil, E., … Wimberly, M. C. (2017). Integrating malaria surveillance with climate data for outbreak detection and forecasting: The EPIDEMIA system. *Malaria Journal*, *16*(1), 89. https://doi.org/10.1186/s12936-017-1735-x

Nkumama, I. N., O'Meara, W. P., & Osier, F. H. A. (2017). Changes in Malaria Epidemiology in Africa and New Challenges for Elimination. *Trends in Parasitology*, *33*(2), 128–140. https://doi.org/10.1016/j.pt.2016.11.006

Quan, V., Hulth, A., Kok, G., & Blumberg, L. (2014). Timelier Notification and Action with Mobile Phones–Towards Malaria Elimination in South Africa. *Malaria Journal*, *13*(1), 151. https://doi.org/10.1186/1475-2875-13-151

Roy, M., Bouma, M., Dhiman, R. C., & Pascual, M. (2015). Predictability of epidemic malaria under non-stationary conditions with process-based models combining epidemiological updates and climate variability. *Malaria Journal*, *14*(1), 419. https://doi.org/10.1186/s12936-015-0937-3

The malERA Consultative Group on Monitoring, Evaluation, and Surveillance. (2011). A Research Agenda for Malaria Eradication: Monitoring, Evaluation, and Surveillance. *PLoS Medicine*, *8*(1), e1000400. https://doi.org/10.1371/journal.pmed.1000400

UCSF Global Health Sciences. (2014). Ideal surveillance for malaria elimination. Retrieved October 4, 2019, from https://globalhealthsciences.ucsf.edu/sites/globalhealthsciences.ucsf.edu/files/pub/mei-pb-surveillance-systems-to-facilitate.pdf

van Eijk, A. M., Ramanathapuram, L., Sutton, P. L., Kanagaraj, D., Sri Lakshmi Priya, G., Ravishankaran, S., … Eapen, A. (2016). What Is the Value of Reactive Case Detection in Malaria Control? A Case-Study in India and a Systematic Review. *Malaria Journal*, *15*(1), 67. https://doi.org/10.1186/s12936-016-1120-1

Whittaker, M., & Smith, C. (2015). Reimagining malaria: Five reasons to strengthen community engagement in the lead up to malaria elimination. *Malaria Journal*, *14*(1), 410. https://doi.org/10.1186/s12936-015-0931-9

World HealthOrganization. (2018). *World Malaria Report 2018*. Retrieved from https://apps.who.int/iris/bitstream/handle/10665/275867/9789241565653-eng.pdf?ua=1.