Received: 6 February 2020 | Revised: 4 June 2020 | Accepted: 16 June 2020

DOI: 10.1002/app5.315

SPECIAL ISSUE

ASIA & THE PACIFIC POLICY STUDIES

Addressing hard-to-reach populations for achieving malaria elimination in the Asia Pacific Malaria Elimination Network countries

Kinley Wangdi[1] | **Ayodhia Pitaloka Pasaribu**[2] | **Archie C.A. Clements**[3,4]

[1]Department of Global Health, Research School of Population Health, Australian National University, Canberra, Australia

[2]Department of Child Health, Medical Faculty, Universitas Sumatera Utara, Indonesia

[3]Faculty of Health Sciences, Curtin University, Perth, WA, Australia

[4]Telethon Kids Institute, Nedlands, Australia

Correspondence
Kinley Wangdi, Department of Global Health, Research School of Population Health, Australian National University, Canberra, Australia.
Email: kinley.wangdi@anu.edu.au

Abstract

Member countries of the Asia Pacific Malaria Elimination Network are pursuing the regional goal of malaria elimination by 2030. The countries are in different phases of malaria elimination, but most have demonstrated success in shrinking the malaria map in the region. However, continued transmission in hard-to-reach populations, including border and forest malaria, remains an important challenge. In this article, we review strategies for improving intervention coverage in hard-to-reach populations. Currently available preventive measures, including long-lasting insecticidal nets and long-lasting insecticidal hammocks, and prompt diagnosis and treatment need to be expanded to hard-to-reach populations. This can be done through mobile malaria clinics, village volunteer malaria workers and screening posts. Malaria surveillance in the hard-to-reach areas can be enhanced through tools such as spatial decision support systems. Policy changes by the malaria programs will be required for implementing the strategies outlined in this article. However, strategies or tools may be suitable for some population groups but difficult to implement in other groups.

KEYWORDS

APMEN, challenges, elimination, hard-to-reach populations, malaria

1 | BACKGROUND

The Asia Pacific Malaria Elimination Network (APMEN) was established in 2009 by 10 countries pursuing the national goal of eliminating malaria. These countries are Bhutan, China, Democratic People's Republic of Korea (DPR Korea), Indonesia, Malaysia, the Philippines, Republic of Korea, Solomon Islands, Sri Lanka and Vanuatu. It has now expanded to 21 countries including Afghanistan, Bangladesh, Cambodia, Lao People's Democratic Republic (Lao PDR), India, Myanmar, Nepal, Papua New Guinea, Thailand, Timor-Leste and Vietnam (Gosling et al., 2012; Wangdi & Clements, 2018). These countries encompass the largest number of malaria cases outside the sub-Saharan African region. APMEN liaises with the Ministries of Health and with regional partners from the academic, development, non-governmental and private sectors, and global agencies including the World Health Organization (WHO), to address the unique challenges of malaria elimination in the region. APMEN works through leadership, advocacy, capacity building, knowledge exchange and building evidence to support more effective, sustained malaria elimination programs across the region (Asia Pacific Malaria Elimination Network [APMEN], 2014).

Each member state has defined elimination goals based on malaria transmission trends. Countries with a low incidence of malaria are targeting elimination at the national level, while countries with a higher incidence are planning to eliminate malaria at the sub-national level before pursuing elimination at the national level. However, all countries are committed to eliminating malaria in the Asia-Pacific region by 2030 (Department of Foreign Affairs and Trade, 2014). Sri Lanka eliminated malaria in 2012 and WHO certified Sri Lanka a malaria-free nation in 2016 (World Health Organization [WHO], 2016a). Bhutan, Bangladesh, China, Malaysia, the Philippines and Vanuatu plan to eliminate malaria by 2020; and the Republic of Korea aims to be malaria free by 2023 (WHO, 2020). DPR Korea, Cambodia, Lao PDR and Papua New Guinea are planning to eliminate by 2025, and Nepal by 2026; finally India, Indonesia, Thailand and Vietnam plan to eliminate malaria by 2030 (APMEN, 2016).

In the elimination phase when total numbers of malaria cases are declining, transmission tends to occur sporadically within distinct foci (Clements et al., 2013; Feachem et al., 2010; Kelly et al., 2012; WHO, 2012b). These distinct foci are often hard-to-reach areas including international border and forested areas. Malaria control in these areas can be difficult to manage due to political, economic and geographic constraints (Cui et al., 2018; Gueye et al., 2012; Kar et al., 2014; Wangdi et al., 2016; Xu & Liu, 2012). In addition, poor access to healthcare and control measures including long-lasting insecticidal nets (LLINs) and frequent movement of populations leave space for malaria reservoirs (Cotter et al., 2013; Dharmawardena et al., 2015; Pindolia et al., 2012). This is further aggravated through poor adherence to preventive measures (Canavati et al., 2019; Grietens et al., 2010). Hard-to-reach populations can act as a source of infection, which can derail the gains made in reducing malaria cases in the general population. Therefore, a policy change in managing malaria in these hard-to-reach areas needs to be undertaken in earnest. The success of malaria elimination in the APMEN states will greatly enhance the global drive towards malaria elimination. The APMEN countries include the current global epicentre of artemisinin resistance—Cambodia, China (Yunnan Province), Lao PDR, Myanmar, Thailand and Vietnam (WHO, 2016a)—and the elimination of malaria in this region will be a major step towards dealing with the burgeoning problem of antimalarial drug resistance. Therefore, this narrative review aims to identify the challenges of malaria elimination in mobile populations in the APMEN countries and propose strategies for improving intervention coverage in hard-to-reach populations.

2 | CHALLENGES FOR MALARIA ELIMINATION IN HARD-TO-REACH POPULATIONS

Nearly 2.1 billion people in the Asia-Pacific region live in areas where there is a risk of malaria transmission, with 16.8% of the Asia-Pacific total population living in high-risk areas (APLMA, 2017; WHO, 2016b). These high-risk areas include settlements located in remote parts of endemic countries, particularly in border areas. Many of these high-risk areas are characterised by forest and forest-fringe environments with high malaria transmission, poor geographical accessibility, high population mobility and low human density (Thomson et al., 2019). Many of these areas are inhabited by ethnic minorities, refugees and displaced people who have difficulties in accessing healthcare and often experience a high degree of poverty (Bui et al., 2011; Erhart et al., 2005).

Additionally, these areas are frequented by people engaged in activities with increased risk of malaria exposure, such as tourism and pilgrimages, and forest-related work including logging, gem-mining, latex harvesting, fishing, road construction and other industrial occupations (Erhart et al., 2004; Erhart et al., 2005; Grietens et al., 2012; Liu et al., 2014; Pichainarong & Chaveepojnkamjorn, 2004). Some forest-goers have described how it is inconvenient to carry bed nets with them and other essential items are prioritised instead (Grietens et al., 2010; Lyttleton, 2016). New to the community, they often have limited knowledge of public health services in the area, including ways to prevent malaria, and many seek antimalarial drugs from unregulated, private vendors (Grietens et al., 2015). These forest-goers, mostly males, can come from malaria-free regions with little or no immunity to malaria (Dysoley et al., 2008). Malaria transmission in forest areas is a complex process involving an interplay between topographical, entomological, parasitological and human factors.

Most current malaria control programs are not resourced to integrate approaches such as mobile malaria workers, village malaria workers and screening posts through the implementation of outreach clinics in remote areas or target hard-to-access population groups as part of routine services. Limited studies on such approaches have shown to be effective in reducing malaria in remote and far-flung areas (Wang et al., 2016). This is challenging to many countries in the region as they struggle to provide routine health services for their citizens (McMichael & Healy, 2017). It is further aggravated by shortages and high attrition rates of health workers in remote communities (Kanchanachitra et al., 2011). The hard-to-reach populations often have unofficial status and few economic resources and can be difficult to locate for effective implementation of malaria control and management strategies (Stern, 1998). Poor adherence to measures which prevent contact with vectors, for example LLINs, long-lasting insecticidal hammocks (LLIHs) and mosquito repellents (Grietens et al., 2010), puts them at an increased risk of acquiring malaria.

Vector control in these areas is difficult due to the behavioural characteristics of *Anopheles dirus* (exophagic, exophilic and early biters), which limits the effectiveness of

LLINs, LLIHs and indoor residual spraying (IRS) for these populations (Jacobson et al., 2017; Trung et al., 2005). Therefore, effective tools to prevent malaria transmission in the early evening and in the early morning, when LLINs cannot be used, need to be developed (Van Bortel et al., 2010). The presence of the highly efficient forest malaria vector *An. minimus s.s.* leads to intense transmission of malaria in remote areas (Dev et al., 2003, 2004; Sanh et al., 2008; SEARO, 2017). New interventions based on insecticide-treated materials need to be urgently evaluated (Erhart et al., 2004; Gryseels et al., 2015). Deforestation and control measures are associated with residual transmission by secondary vectors when the primary vectors such as *An. dirus* or *An. minimus* are reduced (Durnez et al., 2013; Hawkes et al., 2019; Saxena et al., 2014; Wang et al., 2015; Wongsrichanalai et al., 2007; Yasuoka & Levins, 2007). Furthermore, deforestation increases malaria risk by creating mosquito-breeding sites in the stumps of trees, ditches and puddles on the ground. In the deforested areas, there is increased human activity, such as for logging, collecting of wood for fuel, mining and agriculture, which increases exposure to bites from mosquitoes and transmission of malaria (Gryseels et al., 2015; Guerra et al., 2006).

Cross-border movement of populations is another underlying reason for the maintenance of 'hotspots' of high transmission along international borders (Dhiman et al., 2010; Wangdi et al., 2011, 2015, 2016b) and has been a major driver of the spread of drug-resistant malaria along the international border of Thailand and Cambodia (Bhumiratana et al., 2013). Therefore, cross-border data sharing on insecticide resistance, blood testing at the border areas and treatment of symptomatic cases should be prioritised (Edwards et al., 2015; Gueye et al., 2012). Such cross-border initiatives in the region have led to significant reductions in malaria burden in some areas (Xu et al., 2016).

2.1 | Malaria control in hard-to-reach populations

Improved access to malaria diagnosis and care, and preventive interventions such as LLINs, are essential to achieving malaria elimination in the Asia-Pacific region. Equity in access to services including prompt detection and radical treatment of malaria cases in hard-to-reach populations is critical for malaria elimination and sustaining malaria elimination efforts. Improving access to prompt diagnosis and treatment is one of the core aims of the WHO Global Technical Strategy for Malaria 2016–2030 (WHO, 2015a).

Commonly used vector control measures such as IRS are not possible in many hard-to-reach areas because of logistical difficulties. The benefits of a high coverage of LLINs in the general population in reducing malaria is well known (Fokam et al., 2016; Wangdi et al., 2018; WHO, 2007). However, the provision of LLINs to mobile and migrant populations, especially in hard-to-reach areas, remains a challenge (WHO, 2015b). Prompt diagnosis and treatment in hard-to-reach populations, including mobile and migrant populations, are not routinely done in most countries in the APMEN region (Wen et al., 2016).

Mobile malaria clinics offer a promising solution to these challenges. Studies have shown that such initiatives are effective in getting malaria services to the hard-to-reach population (ALIMA, 2017; Kheang et al., 2018; United Nations Development Programme, 2013). Mobile teams can complement routine health facility-based and community-based malaria testing and treatment services. A study in Myanmar has shown that a mobile malaria clinic was able to service more people with malaria services and malaria information with wider geographical coverage (Kheang et al., 2018). Mobile malaria clinics can use mobile phone tracking to find hard-to-reach populations particularly in remote forest areas. However, this approach needs further operational studies to be adopted by the ministries of health in the region.

Village volunteer malaria workers can be used for early diagnosis and prompt treatment of malaria in hard-to-reach areas. The volunteers need to be trained to identify common signs and symptoms, do blood-based rapid diagnostic tests (RDTs) and interpret test results. The two main advantages of this approach are that training is easy and the village volunteers have a strong network within the community residents (increasing access and compliance). This means they are readily available to help locals and migrants recognise malaria symptoms, diagnose malaria with RDTs, treat simple malaria according to national malaria treatment guidelines and monitor treatment adherence. They can also provide malaria education to community members, and refer complicated cases and pregnant women to the health centres. In addition, they can provide information to mobile malaria clinic teams on any members of the community who go to the forest that may need follow up and treatment. However, some of the foreseeable challenges are stock-outs and ways to ensure all the required RDTs, anti-malarial drugs and preventive measures are available to the village volunteers.

Screening posts could serve as an important service point for mobile populations. They can be set up at border crossings and migration portals such as taxi stands, and public bus and boat terminals. These posts can be used to provide intervention packages such as LLINs and LLIHs, pamphlets on malaria (signs and symptoms) and possible contact points for malaria diagnosis and treatment services in the destination area, and education on malaria prevention. Further, free screening and treatment for asymptomatic malaria can be offered for both returning and travelling migrants (Edwards et al., 2015). The posts can also be used to collect information on the destination of the travellers and inform relevant public health officials in the destination areas for follow up. This can help prevent the introduction of malaria into the communities when the mobile population return after work-related travel. Furthermore, treatment of asymptomatic cases can reduce sources of infection from fellow workers or travellers at the destination.

2.2 | Malaria surveillance in hard-to-reach populations

Malaria surveillance systems of countries embarking on malaria elimination need revamping. There is a shift from population to case-based surveillance as countries progress from the control to elimination phase (WHO, 2012a, 2012b). Transforming malaria surveillance to core intervention strategies has been outlined in the Global Technical Strategy for Malaria 2016–2030 (WHO, 2015a).

In most countries in the Asia-Pacific region, malaria surveillance is based on passive case detection. Passive surveillance involves reporting malaria cases by a health facility, which can be limited by incomplete reporting, healthcare seeking in the private sector (not captured by government systems) and poor diagnostic capacity, particularly in low transmission settings and hard-to-reach areas (Singh et al., 2016). Therefore, hard-to-reach populations are not captured by the routine surveillance system. There is a need for the national malaria program to initiate strategies for enumerating populations and conducting surveys in these groups including mass blood screening and geo-referencing these sites. The information from these activities can be used for resource mobilisation and to tailor preventive measures.

To support case-based surveillance in the elimination setting, spatial decision support systems (SDSS) have been used by some countries in the Asia-Pacific region (Kelly et al., 2011;

Ngo et al., 2019; Wangdi et al., 2016a). SDSS facilitates enhanced surveillance, primarily as a means for locating malaria transmission, identifying and targeting appropriate foci-specific interventions and ensuring these interventions are implemented at optimal levels of coverage. A novel extension of the SDSS framework was implemented in managing remote forest dwellers in Vietnam (Ngo et al., 2019). This customised SDSS targeted reactive case detection, enumeration of remote area sleeping sites and intervention. Vector control activities, including IRS and distribution of LLINs and LLIHs, were intensified using the supportive management applications of the SDSS (Canavati, 2017).

Risk mapping and temporal forecasting of malaria using climatic and environmental factors as spatial and temporal risk predictors have been routinely undertaken (Hasyim et al., 2018; Wangdi et al., 2018, 2020). Environmental covariates for geospatial analysis are obtained from satellite sensors and meteorological stations (Dlamini et al., 2015; Hay et al., 2006; Wangdi et al., 2010, 2020). Meteorological data can be interpolated with statistical techniques to estimate values of climatic variables, such as rainfall, temperature and humidity, for locations where meteorological data are not available (Hay & Lennon, 1999). Currently, these approaches have mainly been used in a research context and more operational research needs to be conducted to establish how these approaches can be of practical benefit to hard-to-reach populations.

Traditionally, spatial patterns of malaria risk have been displayed for large geographical units, such as district, province, national, regional and global scales (Clements et al., 2009; Hundessa et al., 2016). However, such low resolution may mask more localised underlying patterns of disease through averaging (Haddow et al., 2009). Therefore, use of finer geographic units may be necessary to observe important local variation in spatial patterns of malaria risk and to better guide disease control efforts and resource allocation, particularly when transmission declines to levels favourable to the pursuit of elimination (Clements et al., 2013; Weiss et al., 2019).

3 | A WAY FORWARD

In the 10 years since APMEN was established, member countries have significantly progressed in reducing the malaria burden in the region. As countries aspire to eliminate malaria in the region by 2030 there are foreseeable challenges that are likely to impede the regional goal of malaria elimination. The challenges include reservoirs of residual malaria in the hard-to-reach populations and inefficient surveillance systems.

As APMEN countries approach malaria elimination, a sticking point will be malaria burden in the hard-to-reach populations. Malaria control and treatment services need to be accessible to these hard-to-reach populations. This can be achieved through malaria mobile clinics, malaria village volunteer workers and screening posts. These innovative approaches offer a way forward to capture mobile and migrant populations in hard-to-reach areas for malaria services.

Migrants can be provided with information on malaria risk, services available and prevention methods including LLINs and LLIHs. Information can be provided through predeparture and on-the-way education at screening posts (Khamsiriwatchara et al., 2011; Wangroongsarb et al., 2011) and by mobile malaria clinics. Additional resources such as short message service (SMS) can be used to disseminate information on malaria prevention and control.

Operational challenges include the high cost of providing these services, monitoring of village health volunteers by health workers (Kheang et al., 2018), and resources and capacity of the national malaria program (Wen et al., 2016). Another operational issue with outreach services is the low level of trust of the people in the hard-to-reach areas including forests towards the government. These populations include hill tribes (Pichainarong & Chaveepojnkamjorn, 2004), refugees (Lee et al., 2006; Parker et al., 2015) and illegal economic migrants (Khamsiriwatchara et al., 2011). Because of their unofficial status, they are not only often hard to reach but may not readily avail themselves of government services (Huguet & Punpuing, 2005; Stern, 1998). A policy change in addressing this issue is important and timely so that these vulnerable populations are covered by malaria preventive and control measures irrespective of their legal status (Harkins, 2019; Inkochasan et al., 2019).

Malaria surveillance systems in the elimination phase aim to detect all infections (both symptomatic and asymptomatic) and ensure radical cure (WHO, 2012b). Most countries in the Asia-Pacific region still continue to use surveillance systems designed for the malaria control phase, which are based on passive case detection and preventive action at the population level (WHO, 2012a). Therefore, malaria surveillance should transition to case-based reporting and case investigation (Jacobson et al., 2017). The national malaria program can expand the routine surveillance system to capture hard-to-reach populations by initiating strategies through the enumeration of these populations and conducting surveys. One such approach would be more targeted active surveillance and interventions using SDSS (Keenan, 2003; Kelly et al., 2011; Kelly et al., 2012; Wangdi et al., 2016a). Continued operational research in hard-to-reach populations needs to be incorporated as part of the routine surveillance system.

4 | CONCLUSION

As countries in the Asia-Pacific region aim to eliminate malaria by 2030, currently available preventive measures, including LLIN, LLIH, and prompt diagnosis and treatment, need to be expanded to hard-to-reach populations. This can be done through mobile malaria clinics, village volunteer malaria workers and screening posts. Malaria surveillance in the hard-to-reach areas can be enhanced through the development and implementation of SDSS. Policy changes by national malaria programs of APMEN countries will be required for implementing the strategies outlined here. However, strategies or tools may be suitable for some population groups but difficult to implement in other groups.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

FUNDING INFORMATION

No funding for this study.

CONTRIBUTIONS

Kinley Wangdi conceived the overall study and undertook literature review and drafted the manuscript. Archie CA Clements assisted in the interpretation of the findings and was involved in the critical revision of the manuscript. Ayodhia Pitaloka Pasaribu was involved in the revision of manuscript. All authors read and approved the final manuscript.

DATA AVAILABILITY STATEMENT

A copy of all reviewed documents is available from the first author upon reasonable request.

ORCID

Kinley Wangdi https://orcid.org/0000-0002-8857-2665

REFERENCES

ALIMA. (2017). South Sudan: Mobile clinic respond to malaria peaks. Retrieved from https://www.alima-ngo.org/en/south-sudan-mobile-clinics-respond-to-malaria-peak

APLMA. (2017). Overview: Malaria in the Asia-Pacific. Retrieved from un.org.au/files/2014/04/Malaria-in-the-Asia-Pacific-WMD-2014.pdf

Asia Pacific Malaria Elimination Network. (2014). APMEN VI: A declaration of continued commitment to eliminate malaria in the Asia Pacific.

Asia Pacific Malaria Elimination Network. (2016). Malaria elimination goals. Retrieved from http://apmen.org/web/1/elimination/

Bhumiratana, A., Intarapuk, A., Sorosjinda-Nunthawarasilp, P., Maneekan, P., & Koyadun, S. (2013). Border malaria associated with multidrug resistance on Thailand-Myanmar and Thailand-Cambodia borders: Transmission dynamic, vulnerability, and surveillance. *BioMed Research International*, *2013*, 363417. https://doi.org/10.1155/2013/363417

Bui, H. M., Clements, A. C. A., Nguyen, Q. T., Nguyen, M. H., Le, X. H., Hay, S. I., … Horby, P. (2011). Social and environmental determinants of malaria in space and time in Viet Nam. *International Journal for Parasitology*, *41*(1), 109–116. https://doi.org/10.1016/j.ijpara.2010.08.005

Canavati, S. E. (2017, December 6). A spatial decision support system approach to implementing malaria surveillance as a core intervention activity in high priority Vietnam. Paper presented at the Joint International Tropical Medicine Meeting 2017, Bangkok, Thailand.

Canavati, S. E., Kelly, G. C., Quintero, C. E., Vo, T. H., Tran, L. K., Ohrt, C., … Martin, N. J. (2019). Risk factor assessment for clinical malaria among forest-goers in a pre-elimination setting in Phu Yen Province, Vietnam. *Malaria Journal*, *18*, 435. https://doi.org/10.1186/s12936-019-3068-4

Clements, A. C. A., Barnett, A. G., Cheng, Z. W., Snow, R. W., & Zhou, H. N. (2009). Space-time variation of malaria incidence in Yunnan province, China. *Malaria Journal*, *8*, 180. https://doi.org/10.1186/1475-2875-8-180

Clements, A. C. A., Reid, H. L., Kelly, G. C., & Hay, S. I. (2013). Further shrinking the malaria map: How can geospatial science help to achieve malaria elimination? *The Lancet Infectious Disease*, *13*(8), 709–718. https://doi.org/10.1016/S1473-3099(13)70140-3

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

Cui, L., Cao, Y., Kaewkungwal, J., Khamsiriwatchara, A., Lawpoolsri, S., Soe, T. N., … Sattabongkot, J. (2018). Malaria elimination in the Greater Mekong Subregion: Challenges and prospects. In S. Manguin, & V. Dev (Eds.), *Towards malaria elimination* (pp. 179–200). London: IntechOpen. https://doi.org/10.5772/intechopen.76337

Department of Foreign Affairs and Trade. (2014, November 13). Chairman's Statement of 9th East Asia Summit, Nay Pyi Taw, Myanmar. Retrieved from http://dfat.gov.au/international-relations/regional-architecture/eas/Pages/chairmans-statement-of-the-9th-east-asia-summit.aspx

Dev, V., Bhattacharyya, P. C., & Talukdar, R. (2003). Transmission of malaria and its control in the northeastern region of India. *Journal of the Association of Physicians of India*, *51*, 1073–1076.

Dev, V., Phookan, S., Sharma, V. P., & Anand, S. P. (2004). Physiographic and entomologic risk factors of malaria in Assam, India. *American Journal of Tropical Medicine and Hygiene*, *71*(4), 451–456. https://doi.org/10.4269/ajtmh.2004.71.451

Dharmawardena, P., Premaratne, R. G., Gunasekera, W. M., Hewawitarane, M., Mendis, K., & Fernando, D. (2015). Characterization of imported malaria, the largest threat to sustained malaria elimination from Sri Lanka. *Malaria Journal*, *14*, 177. https://doi.org/10.1186/s12936-015-0697-0

Dhiman, S., Goswami, D., Rabha, B., Gopalakrishnan, R., Baruah, I., & Singh, L. (2010). Malaria epidemiology along Indo-Bangladesh border in Tripura State, India. *Southeast Asian Journal of Tropical Medicine and Public Health*, *41*(6), 1279–1289.

Dlamini, S. N., Franke, J., & Vounatsou, P. (2015). Assessing the relationship between environmental factors and malaria vector breeding sites in Swaziland using multi-scale remotely sensed data. *Geospatial Health*, *10*(1). https://doi.org/10.4081/gh.2015.302

Durnez, L., Mao, S., Denis, L., Roelants, P., Sochantha, T., & Coosemans, M. (2013). Outdoor malaria transmission in forested villages of Cambodia. *Malaria Journal*, *12*, 329. https://doi.org/10.1186/1475-2875-12-329

Dysoley, L., Kaneko, A., Eto, H., Mita, T., Socheat, D., Börkman, A., & Kobayakawa, T. (2008). Changing patterns of forest malaria among the mobile adult male population in Chumkiri District, Cambodia. *Acta Tropica*, *106*(3), 207–212. https://doi.org/10.1016/j.actatropica.2007.01.007

Edwards, H. M., Canavati, S. E., Rang, C., Ly, P., Sovannaroth, S., Canier, L., … Roca-Feltrer, A. (2015). Novel cross-border approaches to optimise identification of asymptomatic and artemisinin-resistant *Plasmodium* infection in mobile populations crossing Cambodian borders. *PLoS ONE*, *10*(9), e0124300. https://doi.org/10.1371/journal.pone.0124300

Erhart, A., Ngo, D. T., Phan, V. K., Ta, T. T., Van Overmeir, C., Speybroeck, N., … D'alessandro, U. (2005). Epidemiology of forest malaria in central Vietnam: A large scale cross-sectional survey. *Malaria Journal*, *4*, 58. https://doi.org/10.1186/1475-2875-4-58

Erhart, A., Thang, N. D., Hung, N. Q., Toi, L. V., Hung, L. X., Tuy, T. Q., … D'alessandro, U. (2004). Forest malaria in Vietnam: A challenge for control. *American Journal of Tropical Medicine and Hygiene*, *70*(2), 110–118. https://doi.org/10.4269/ajtmh.2004.70.110

Feachem, R. G., Phillips, A. A., Hwang, J., Cotter, C., Wielgosz, B., Greenwood, B. M., Sabot, O., Rodriguez, M. H., Abeyasinghe, R. R., Ghebreyesus, T. A., & Snow, R. W. (2010). Shrinking the malaria map: Progress and prospects. *The Lancet*, *376*(9752), 1566–1578. https://doi.org/10.1016/S0140-6736(10)61270-6

Fokam, E. B., Dzi, K. T., Ngimuh, L., & Enyong, P. (2016). The effect of long lasting insecticide bed net use on malaria prevalence in the Tombel Health District, South West Region-Cameroon. *Malaria Research and Treatment*, *2016*, 3216017. https://doi.org/10.1155/2016/3216017

Gosling, R. D., Whittaker, M., Gueye, C. S., Fullman, N., Baquilod, M., Kusriastuti, R., & Feachem, R. G. (2012). Malaria elimination gaining ground in the Asia Pacific. *Malaria Journal*, *11*, 346. https://doi.org/10.1186/1475-2875-11-346

Grietens, K. P., Gryseels, C., Dierickx, S., Bannister-Tyrrell, M., Trienekens, S., Uk, S., … Erhart, A. (2015). Characterizing types of human mobility to inform differential and targeted malaria elimination strategies in Northeast Cambodia. *Scientific Reports*, *5*, 16837. https://doi.org/10.1038/srep16837

Grietens, K. P., Xuan, X. N., Ribera, J. M., Duc, T. N., van Bortel, W., Ba, N. T., … Erhart, A. (2012). Social determinants of long lasting insecticidal hammock-use among the Ra-glai ethnic minority in Vietnam: Implications for forest malaria control. *PLoS ONE*, *7*(1), 29991. https://doi.org/10.1371/journal.pone.0029991

Grietens, K. P., Xuan, X. N., van Bortel, W., Duc, T. N., Ribera, J. M., Nhat, T. B., … Erhart, A. (2010). Low perception of malaria risk among the Ra-glai ethnic minority in south-central Vietnam: Implications for forest malaria control. *Malaria Journal*, *9*, 23. https://doi.org/10.1186/1475-2875-9-23

Gryseels, C., Durnez, L., Gerrets, R., Uk, S., Suon, S., Set, S., … Grietens, K. P. (2015). Re-imagining malaria: Heterogeneity of human and mosquito behaviour in relation to residual malaria transmission in Cambodia. *Malaria Journal*, *14*, 165. https://doi.org/10.1186/s12936-015-0689-0

Guerra, C. A., Snow, R. W., & Hay, S. I. (2006). A global assessment of closed forests, deforestation and malaria risk. *Annals of Tropical Medicine and Parasitology*, *100*(3), 189–204. https://doi.org/10.1179/136485906X91512

Gueye, C. S., Teng, A., Kinyua, K., Wafula, F., Gosling, R., & McCoy, D. (2012). Parasites and vectors carry no passport: How to fund cross-border and regional efforts to achieve malaria elimination. *Malaria Journal*, *11*, 344. https://doi.org/10.1186/1475-2875-11-344

Haddow, A. D., Jones, C. J., & Odoi, A. (2009). Assessing risk in focal arboviral infections: Are we missing the big or little picture? *PLoS ONE*, *4*(9), e6954. https://doi.org/10.1371/journal.pone.0006954

Harkins, B. (Ed.) (2019). *Thailand migration report 2019*. Bangkok: United Nations Thematic Working Group on Migration in Thailand. Retrieved from https://thailand.iom.int/thailand-migration-report-2019-0

Hasyim, H., Nursafingi, A., Haque, U., Montag, D., Groneberg, D. A., Dhimal, M., … Müller, R. (2018). Spatial modelling of malaria cases associated with environmental factors in South Sumatra, Indonesia. *Malaria Journal*, *17*, 87. https://doi.org/10.1186/s12936-018-2230-8

Hawkes, F. M., Manin, B. O., Cooper, A., Daim, S., Homathevi, R., Jelip, J., … Chua, T. H. (2019). Vector compositions change across forested to deforested ecotones in emerging areas of zoonotic malaria transmission in Malaysia. *Scientific Reports*, *9*(1), 13312. https://doi.org/10.1038/s41598-019-49842-2

Hay, S. I., & Lennon, J. J. (1999). Deriving meteorological variables across Africa for the study and control of vector-borne disease: A comparison of remote sensing and spatial interpolation of climate. *Tropical Medicine & International Health*, *4*(1), 58–71. https://doi.org/10.1046/j.1365-3156.1999.00355.x

Hay, S. I., Tatem, A. J., Graham, A. J., Goetz, S. J., & Rogers, D. J. (2006). Global environmental data for mapping infectious disease distribution. *Advances in Parasitology*, *62*, 37–77. https://doi.org/10.1016/S0065-308X(05)62002-7

Huguet, J. W., & Punpuing, S. (Eds.) (2005). *International migration in Thailand*. Bangkok: International Organization for Migration.

Hundessa, S. H., Williams, G., Li, S., Guo, J., Chen, L., Zhang, W., & Guo, Y. (2016). Spatial and space-time distribution of *Plasmodium vivax* and *Plasmodium falciparum* malaria in China, 2005–2014. *Malaria Journal*, *15*, 595. https://doi.org/10.1186/s12936-016-1646-2

Inkochasan, M., Gopinath, D., Vicario, E., Lee, A., & Duigan, P. (2019). Access to health care for migrants in the Greater Mekong Subregion: Policies and legal frameworks and their impact on malaria control in the context of malaria elimination. *WHO South East Asia Journal of Public Health*, *8*(1), 26–34. https://doi.org/10.4103/2224-3151.255346

Jacobson, J. O., Cueto, C., Smith, J. L., Hwang, J., Gosling, R., & Bennett, A. (2017). Surveillance and response for high-risk populations: What can malaria elimination programmes learn from the experience of HIV? *Malaria Journal*, *16*, 33. https://doi.org/10.1186/s12936-017-1679-1

Kanchanachitra, C., Lindelow, M., Johnston, T., Hanvoravongchai, P., Lorenzo, F. M., Huong, N. L., … dela Rosa, J. F. (2011). Human resources for health in Southeast Asia: Shortages, distributional challenges, and international trade in health services. *The Lancet*, *377*(9767), 769–781. https://doi.org/10.1016/S0140-6736(10)62035-1

Kar, N. P., Kumar, A., Singh, O. P., Carlton, J. M., & Nanda, N. (2014). A review of malaria transmission dynamics in forest ecosystems. *Parasites & Vectors*, *7*, 265.

Keenan, P. B. (2003). Spatial decision support systems. In G. A. Forgionne, J. N. Gupta, & M. Mora (Eds.), *Decision-making support systems: Achievements and challenges for the new decade* (pp. 28–39). Hershey, Pennsylvania: IGI Global. https://doi.org/10.4018/978-1-59140-045-5.ch003

Kelly, G. C., Seng, C. M., Donald, W., Taleo, G., Nausien, J., Batarii, W., … Clements, A. C. A. (2011). A spatial decision support system for guiding focal indoor residual spraying interventions in a malaria elimination zone. *Geospatial Health*, *6*(1), 21–31. https://doi.org/10.4081/gh.2011.154

Kelly, G. C., Tanner, M., Vallely, A., & Clements, A. C. A. (2012). Malaria elimination: Moving forward with spatial decision support systems. *Trends in Parasitology*, *28*(7), 297–304. https://doi.org/10.1016/j.pt.2012.04.002

Khamsiriwatchara, A., Wangroongsarb, P., Thwing, J., Eliades, J., Satimai, W., Delacollette, C., & Kaewkungwal, J. (2011). Respondent-driven sampling on the Thailand-Cambodia border. I. Can malaria cases be contained in mobile migrant workers? *Malaria Journal*, *10*, 120. https://doi.org/10.1186/1475-2875-10-120

Kheang, S. T., Lin, M. A., Lwin, S., Naing, Y. H., Yarzar, P., Kak, N., & Price, T. (2018). Malaria case detection among mobile populations and migrant workers in Myanmar: Comparison of 3 service delivery approaches. *Global Health, Science and Practice*, *6*(2), 381–386. https://doi.org/10.9745/GHSP-D-17-00318

Lee, T. J., Mullany, L. C., Richards, A. K., Kuiper, H. K., Maung, C., & Beyrer, C. (2006). Mortality rates in conflict zones in Karen, Karenni, and Mon states in eastern Burma. *Tropical Medicine & International Health*, *11*(7), 1119–1127. https://doi.org/10.1111/j.1365-3156.2006.01651.x

Liu, Y., Hsiang, M. S., Zhou, H., Wang, W., Cao, Y., Gosling, R. D., … Gao, Q. (2014). Malaria in overseas labourers returning to China: An analysis of imported malaria in Jiangsu Province, 2001–2011. *Malaria Journal*, *13*, 29. https://doi.org/10.1186/1475-2875-13-29

Lyttleton, C. (2016). Deviance and resistance: Malaria elimination in the greater Mekong subregion. *Social Science & Medicine*, *150*, 144–152. https://doi.org/10.1016/j.socscimed.2015.12.033

McMichael, C., & Healy, J. (2017). Health equity and migrants in the Greater Mekong Subregion. *Global Health Action*, *10*(1), 1271594. https://doi.org/10.1080/16549716.2017.1271594

Ngo, T. D., Canavati, S. E., Dinh, H. S., Ngo, T. D., Tran, D. T., Martin, N. J., & Kelly, G. C. (2019). Addressing operational challenges of combatting malaria in a remote forest area of Vietnam using spatial decision support system approaches. *Geospatial Health*, *14*(2). https://doi.org/10.4081/gh.2019.770

Parker, D. M., Carrara, V. I., Pukrittayakamee, S., McGready, R., & Nosten, F. H. (2015). Malaria ecology along the Thailand-Myanmar border. *Malaria Journal*, *14*, 388. https://doi.org/10.1186/s12936-015-0921-y

Pichainarong, N., & Chaveepojnkamjorn, W. (2004). Malaria infection and life-style factors among hilltribes along the Thai-Myanmar border area, northern Thailand. *Southeast Asian Journal of Tropical Medicine and Public Health*, *35*(4), 834–839.

Pindolia, D. K., Garcia, A. J., Wesolowski, A., Smith, D. L., Buckee, C. O., Noor, A. M., … Tatem, A. J. (2012). Human movement data for malaria control and elimination strategic planning. *Malaria Journal*, *11*, 205. https://doi.org/10.1186/1475-2875-11-205

Sanh, N. H., Van Dung, N., Thanh, N. X., Trung, T. N., Van Co, T., & Cooper, R. D. (2008). Forest malaria in central Vietnam. *American Journal of Tropical Medicine and Hygiene*, *79*(5), 652–654. https://doi.org/10.4269/ajtmh.2008.79.652

Saxena, R., Nagpal, B. N., Singh, V. P., Srivastava, A., Dev, V., Sharma, M. C., … Gupta, S. K. (2014). Impact of deforestation on known malaria vectors in Sonitpur district of Assam, India. *Journal of Vector Borne Diseases*, *51*(3), 211–215.

SEARO (2017). *Malaria vectors of South-East Asia*, W. SEARO.

Singh, N., Bharti, P. K., & Kumre, N. S. (2016). Active v. passive surveillance for malaria in remote tribal belt of Central India: Implications for malaria elimination. *Pathogens and Global Health*, *110*(4–5), 178–184. https://doi.org/10.1080/20477724.2016.1223920

Stern, A. (1998). International population movements and public health in the Mekong region: An overview of some issues concerning mapping. *Southeast Asian J Trop Med Public Health*, *29*(2), 201–212.

Thomson, R., Sochea, P., Sarath, M., MacDonald, A., Pratt, A., Poyer, S., … Yeung, S. (2019). Rubber plantations and drug resistant malaria: A cross-sectional survey in Cambodia. *Malaria Journal*, *18*, 379. https://doi.org/10.1186/s12936-019-3000-y

Trung, H. D., van Bortel, W., Sochantha, T., Keokenchanh, K., Briët, O. J., & Coosemans, M. (2005). Behavioural heterogeneity of *Anopheles* species in ecologically different localities in Southeast Asia: A challenge for vector control. *Tropical Medicine & International Health*, *10*(3), 251–262. https://doi.org/10.1111/j.1365-3156.2004.01378.x

United Nations Development Programme. (2013). In Bangladesh, mobile clinics help fight malaria in remote hills. UNDP Our Stories. Retrieved from https://www.undp.org/content/undp/en/home/ourwork/ourstories/safety-nets–bed-nets-fight-malaria-in-bangladesh.html

Van Bortel, W., Trung, H. D., Hoi, L. X., Van Ham, N., Van Chut, N., Luu, N. D., … Coosemans, M. (2010). Malaria transmission and vector behaviour in a forested malaria focus in central Vietnam and the implications for vector control. *Malaria Journal*, *9*, 373. https://doi.org/10.1186/1475-2875-9-373

Wang, R. B., Dong, J. Q., Xia, Z. G., Cai, T., Zhang, Q., Zhang, Y., … Zhang, J. (2016). Lessons on malaria control in the ethnic minority regions in Northern Myanmar along the China border, 2007–2014. *Infectious Diseases of Poverty*, *5*(1), 95. https://doi.org/10.1186/s40249-016-0191-0

Wang, Y., Zhong, D., Cui, L., Lee, M., Yang, Z., Yan, G., & Zhou, G. (2015). Population dynamics and community structure of Anopheles mosquitoes along the China-Myanmar border. *Parasites & Vectors*, *8*, 445. https://doi.org/10.1186/s13071-015-1057-1

Wangdi, K., Banwell, C., Gatton, M. L., Kelly, G. C., Namgay, R., & Clements, A. C. A. (2016a). Development and evaluation of a spatial decision support system for malaria elimination in Bhutan. *Malaria Journal*, *15*, 180. https://doi.org/10.1186/s12936-016-1235-4

Wangdi, K., Banwell, C., Gatton, M. L., Kelly, G. C., Namgay, R., & Clements, A. C. A. (2016b). Malaria burden and costs of intensified control in Bhutan, 2006–14: An observational study and situation analysis. *The Lancet Global Health*, *4*(5), e336–e343. https://doi.org/10.1016/S2214-109X(16)00083-8

Wangdi, K., Canavati, S. E., Ngo, T. D., Tran, L. K., Nguyen, T. M., Tran, D. T., … Clements, A. C. A. (2018). Analysis of clinical malaria disease patterns and trends in Vietnam 2009–2015. *Malaria Journal*, *17*, 332. https://doi.org/10.1186/s12936-018-2478-z

Wangdi, K., & Clements, A. C. A. (2018). Ending Malaria Transmission in the Asia Pacific Malaria Elimination Network (APMEN) countries: Challenges and the way forward. In S. Manguin, & V. Dev (Eds.), *Towards malaria elimination* (pp. 201–232). London: IntechOpen. https://doi.org/10.5772/intechopen.75405

Wangdi, K., Furuya-Kanamori, L., Clark, J., Barendregt, J. J., Gatton, M. L., Banwell, C., … Clements, A. C. A. (2018). Comparative effectiveness of malaria prevention measures: A systematic review and network meta-analysis. *Parasites & Vectors*, *11*, 210. https://doi.org/10.1186/s13071-018-2783-y

Wangdi, K., Gatton, M. L., Kelly, G. C., Banwell, C., Dev, V., & Clements, A. C. A. (2016). Malaria elimination in India and regional implications. *The Lancet Infectious Diseases*, *16*(10), e214–e224. https://doi.org/10.1016/S1473-3099(16)30123-2

Wangdi, K., Gatton, M. L., Kelly, G. C., & Clements, A. C. A. (2015). Cross-border malaria: A major obstacle for malaria elimination. *Advances in Parasitology*, *89*, 79–107. https://doi.org/10.1016/bs.apar.2015.04.002

Wangdi, K., Kaewkungwal, J., Singhasivanon, P., Silawan, T., Lawpoolsri, S., & White, N. J. (2011). Spatio-temporal patterns of malaria infection in Bhutan: A country embarking on malaria elimination. *Malaria Journal*, *10*, 89. https://doi.org/10.1186/1475-2875-10-89

Wangdi, K., Singhasivanon, P., Silawan, T., Lawpoolsri, S., White, N. J., & Kaewkungwal, J. (2010). Development of temporal modelling for forecasting and prediction of malaria infections using time-series and ARIMAX analyses: A case study in endemic districts of Bhutan. *Malaria Journal*, *9*, 251. https://doi.org/10.1186/1475-2875-9-251

Wangdi, K., Xu, Z., Suwannatrai, A. T., Kurscheid, J., Lal, A., Namgay, R., … Clements, A. C. A. (2020). A spatio-temporal analysis to identify the drivers of malaria transmission in Bhutan. *Scientific Reports*, *10*, 7060. https://doi.org/10.1038/s41598-020-63896-7

Wangroongsarb, P., Satimai, W., Khamsiriwatchara, A., Thwing, J., Eliades, J. M., Kaewkungwal, J., & Delacollette, C. (2011). Respondent-driven sampling on the Thailand-Cambodia border. II. Knowledge, perception, practice and treatment-seeking behaviour of migrants in malaria endemic zones. *Malaria Journal*, *10*, 117. https://doi.org/10.1186/1475-2875-10-117

Weiss, D. J., Lucas, T. C. D., Nguyen, M., Nandi, A. K., Bisanzio, D., Battle, K. E., … Gething, P. W. (2019). Mapping the global prevalence, incidence, and mortality of *Plasmodium falciparum*, 2000–17: A spatial and temporal modelling study. *The Lancet*, *394*(10195), 322–331. https://doi.org/10.1016/S0140-6736(19)31097-9

Wen, S., Harvard, K. E., Gueye, C. S., Canavati, S. E., Chancellor, A., Ahmed, B., … Gosling, R. D. (2016). Targeting populations at higher risk for malaria: A survey of national malaria elimination programmes in the Asia Pacific. *Malaria Journal*, *15*, 271. https://doi.org/10.1186/s12936-016-1319-1

Wongsrichanalai, C., Barcus, M. J., Muth, S., Sutamihardja, A., & Wernsdorfer, W. H. (2007). A review of malaria diagnostic tools: Microscopy and rapid diagnostic test (RDT). *American Journal of Tropical Medicine and Hygiene*, *77*(6 Suppl), 119–127. https://doi.org/10.4269/ajtmh.2007.77.119

World Health Organization. (2007). Insecticide-treated mosquito nets: A WHO position statement. World Health Organization. Retrieved from http://medi-guide.meditool.cn/ymtpdf/FBACA171-AF95-DCFA-673E-3FA3AFEB79AE.pdf

World Health Organization. (2012a). Disease surveillance for malaria control: An operational manual. World Health Organization. Retrieved from https://www.who.int/malaria/publications/atoz/9789241503341/en/

World Health Organization. (2012b). Disease surveillance for malaria elimination: An operational manual. World Health Organization. Retrieved from https://www.who.int/malaria/publications/atoz/9789241503334/en/

World Health Organization. (2015a). Global technical strategy for malaria 2016–2030. World Health Organization. Retrieved from https://www.who.int/malaria/publications/atoz/9789241564991/en/

World Health Organization. (2015b). Strategy for malaria elimination in the Greater Mekong Subregion: 2015–2030. World Health Organization. Retrieved from https://www.who.int/malaria/publications/atoz/eliminating-malaria-greater-mekong/en/

World Health Organization. (2016a). WHO certifies Sri Lanka malaria-free. Retrieved from http://www.searo.who.int/mediacentre/releases/2016/1631/en/

World Health Organization. (2016b). World malaria report 2016. World Health Organization. Retrieved from https://www.who.int/malaria/publications/world-malaria-report-2016/report/en/, DOI: https://doi.org/10.30875/4348b814-en

World Health Organization. (2020). Malaria: Republic of Korea, E-2020 country brief. Retrieved from https://www.who.int/malaria/areas/elimination/e2020/republic-of-korea/en/

Xu, J., & Liu, H. (2012). The challenges of malaria elimination in Yunnan Province, People's Republic of China. *Southeast Asian Journal of Tropical Medicine and Public Health*, *43*(4), 819–824.

Xu, J. W., Li, Y., Yang, H. L., Zhang, J., Zhang, Z., Yang, Y., … Li, B. (2016). Malaria control along China-Myanmar Border during 2007–2013: An integrated impact evaluation. *Infectious Diseases of Poverty*, *5*, 75. https://doi.org/10.1186/s40249-016-0171-4

Yasuoka, J., & Levins, R. (2007). Impact of deforestation and agricultural development on anopheline ecology and malaria epidemiology. *American Journal of Tropical Medicine and Hygiene*, *76*(3), 450–460. https://doi.org/10.4269/ajtmh.2007.76.450

How to cite this article: Wangdi K, Pasaribu AP, Clements ACA. Addressing hard-to-reach populations for achieving malaria elimination in the Asia Pacific Malaria Elimination Network countries. *Asia & the Pacific Policy Studies*. 2021;8:176–188. https://doi.org/10.1002/app5.315