Revolutionizing Vector Control for Malaria Elimination

Identifying the drivers and distribution of residual transmission in Africa using geospatial modeling

Key Messages

- Despite the huge gains in malaria control made through the scale up and use of insecticide-treated nets (ITNs), and to a lesser extent indoor residual spraying (IRS), malaria transmission continues in most countries in sub-Saharan Africa (SSA)
- Using geospatial modeling the Malaria Elimination Initiative (MEI) at the University of California, San Francisco Global Health Group with the Malaria Atlas Project at the University of Oxford (MAP) examined factors that may help to explain why malaria transmission continues in some areas
- Results showed that in areas with high agricultural activity (e.g. areas of intense sugarcane production) and domestic livestock rearing (e.g. areas of high chicken density), the apparent effictiveness of ITNs was reduced
- Factors associated with modernity and urbanization (growth of man-made surfaces, expansion of night time lights and improved housing construction) have contributed, alongside malaria control, to the declines in transmission across the continent
- Even if ITNs were scaled up to a uniform level of 80% coverage across SSA, there would still be substantial residual malaria transmission[A] across the continent due to diverse vector behavior
- Elimination of malaria in SSA, and likely globally, will be impossible without novel vector control tools (VCTs) that tackle residual transmission

Investigating Factors Contributing to Residual Transmission

From 2000 to 2015, malaria burden in Africa has declined dramatically with the number of deaths dropping by half. High coverage of insecticide-treated bednets (ITNs),[2] augmented by indoor residual spraying (IRS) with pyrethroid insecticides, has been found responsible for around 80% of all averted cases over this period.[1] However, it is increasingly recognized that in parts of Africa, and to a possibly larger extent in other regions of the world, high ITN coverage may not be sufficient to reduce transmission to a level where other non-vector-based elimination activities can be successful.[3] Residual transmission, or the transmission that remains once ITNs/IRS have been scaled up, occurs because some infectious bites take place beyond the protection offered by these interventions; for example, outdoors or during the daytime.

Our lack of understanding of the key contributing factors to residual transmission poses a fundamental barrier to elimination. Quantifying residual transmission in Africa and characterizing how it varies from place to place is needed to develop geographically targeted tools for tackling residual transmission.

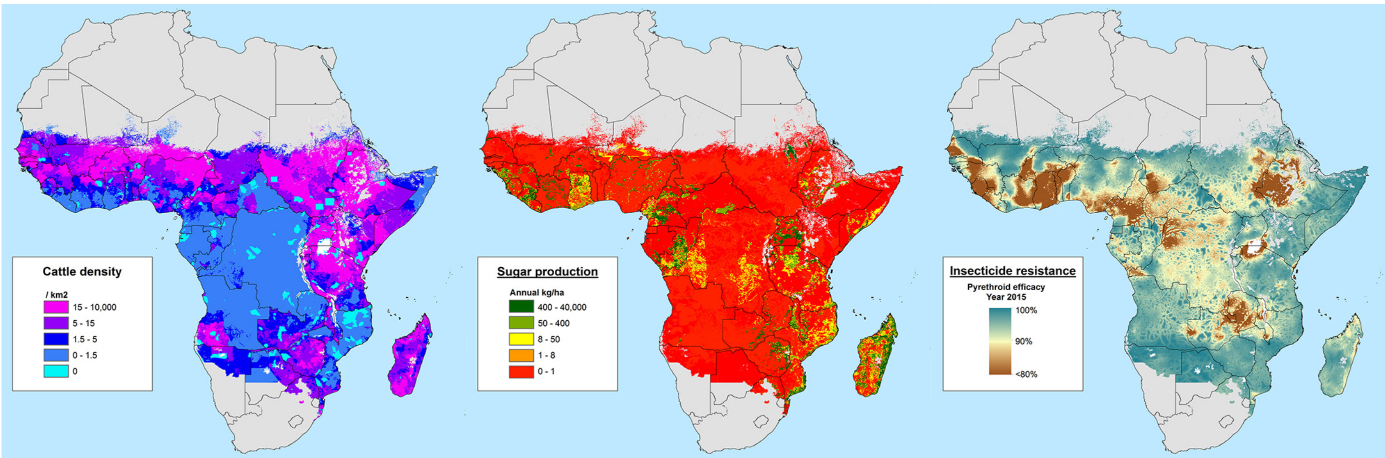
The MEI, in partnership with MAP, used geospatial data modeling to answer three interrelated questions that strengthen the understanding of residual transmission in Africa:

- What human and environmental factors contribute to residual transmission?
- What background factors other than malaria control have reduced transmission across Africa?
- What would be the level of residual transmission across Africa if high coverage of ITNs/IRS was achieved?

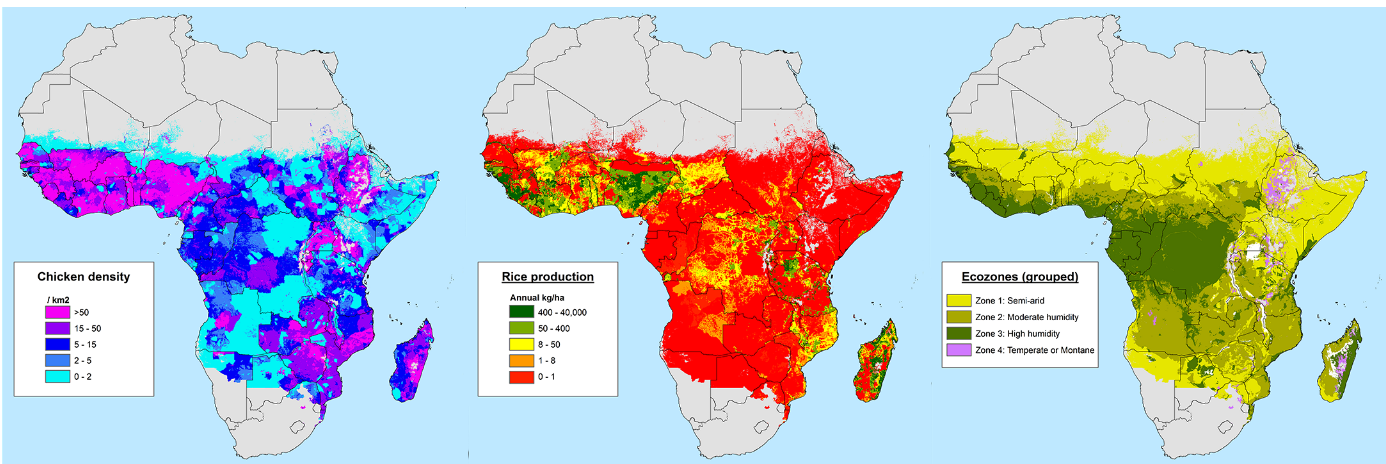
A Residual transmission is malaria transmission that persists despite high coverage of ITNs and/or IRS, to which a combination of human and vector behaviors contribute (e.g. humans sleeping or active unprotected outdoors and vectors resting and biting outdoors, feeding on animals, and evading ITNs/IRS indoors)[1]

Figure 1. Geospatial layers assembled or constructed for the analysis

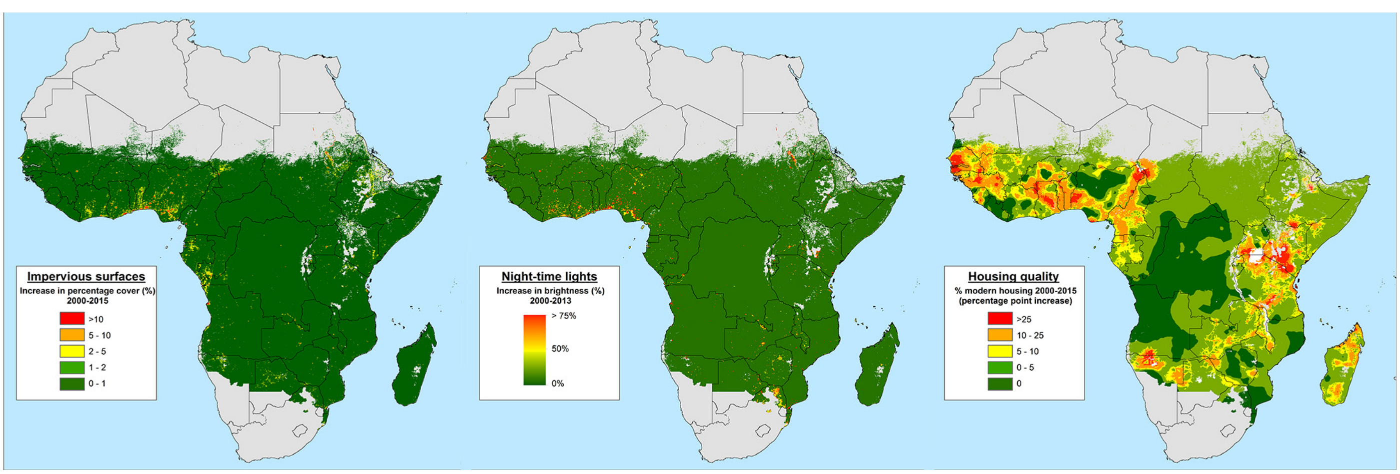
Top and middle rows: potential drivers of ITN effectiveness
Bottom row: independent contributors to declining of transmission



Cattle density | Sugarcane production | Pyrethroid resistance



Chicken density | Rice production | Climate-ecozone



Impervious surfaces (% increase 2000–2015) | Night-time lights (% increase 2000–2015) | Modern housing (% increase 2000–2015)

Geographic Variation in ITN Effectiveness

In an effort to explain why in certain parts of Africa malaria did not decline at the expected rate given the local level of ITN/IRS coverage (proportion of population who slept under an ITN/slept in a sprayed structure), spatial layers of factors that could potentially reduce the effectiveness of ITNs/IRS were generated (Figure 1, on previous page):

- Cattle and chicken density (by providing alternative blood meals to zoophagic vector species, thus reducing contact with ITNs/IRS);
- Rice and sugarcane cultivation (by providing aquatic breeding sites, sugar sources for vector feeding, and increasing outdoor human-vector contact);
- Climatic zone (with more humid areas allowing greater adaptability of vector behavior away from indoor night-time biting); and
- Pyrethroid resistance (which directly reduces the impact of ITNs/IRS on vector populations).[B]

By including these factors in a geospatial model, it was found that agricultural practices such as intensive rice and sugar cane cultivation have significant independent impacts on the effectiveness of ITNs. Cattle density and climate-ecozone were not found to be associated. And, when all factors investigated were combined they jointly led to substantial geographical variation in ITN effectiveness across Africa (Figure 2, below). Areas with markedly reduced effectiveness included extended regions of West Africa and parts of Southeast Africa.

B Definitions of 'residual transmission' usually exclude the effect of insecticide resistance. We include in this analysis so its effect can be separated from the other human/vector behavioral factors addressed.

Urbanization and Socioeconomic Development Contribute to the Decline of Malaria Transmission

Rapid socioeconomic development in sub-Saharan Africa (SSA) since 2000 may have played an important indirect role in reducing transmission. Improvements in housing construction reduce exposure to mosquitoes and urbanization has driven more people to live in urban areas which are less ecologically-suited to sustain malaria vectors. To investigate these factors, dynamic maps showing changes in housing quality and, as metrics of urbanization, the brightness of night-time lights and the presence of man-made surfaces (e.g. roads, rooftops) were generated (Figure 1, bottom row). These factors were then included in the geospatial model to evaluate their influence on declining infection prevalence between 2000 and 2015.

Results showed that both urbanization (represented using the proxy measures of increasing night-time light brightness and impervious surfaces) and improving housing quality were significant contributors to declining malaria transmission since 2000.

Residual Transmission Will Likely Remain High Even If ITN Coverage Was Expanded to 80%

A hypothetical scenario where ITN coverage was expanded to 80% across the entire continent was then modeled. This was used as a hypothetical feasible maximum level of sustained coverage, if large increases of funding were available. The estimated level of residual transmission that would be seen in Africa under this maximum ITN coverage level was then estimated.

Figure 2. Analysis of ITN effectiveness across Africa

A: geographical variation in the predicted relative effectiveness of ITNs
B: predicted prevalence of *Plasmodium falciparum* (*Pf*PR) in 2015 under real-world 2015 ITN coverage levels
C: predicted *Pf*PR in 2015 under a hypothetical 80% ITN scenario, revealing extent and distribution of residual transmission

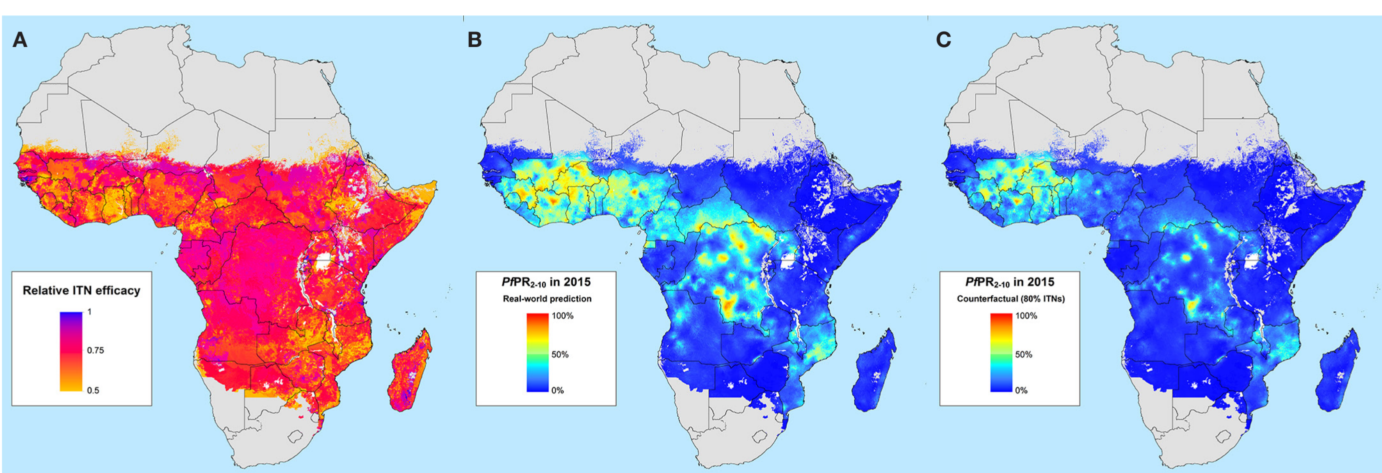
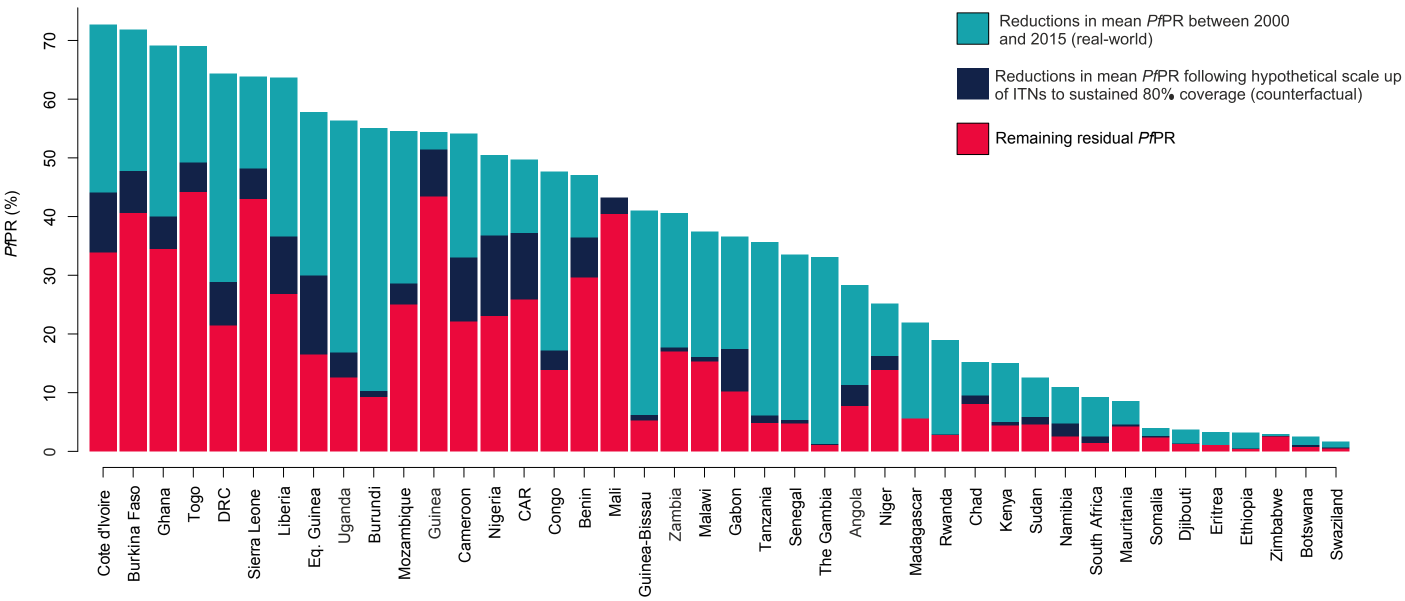


Figure 3. Nearly all countries in Africa have declined in PfPR substantially since 2000 (teal sections)

Scale up of ITNs to sustained 80% use would yield the further declines (navy blue). Residual transmission following this scale-up (red) remains substantial in many countries, both in absolute and proportionate terms.



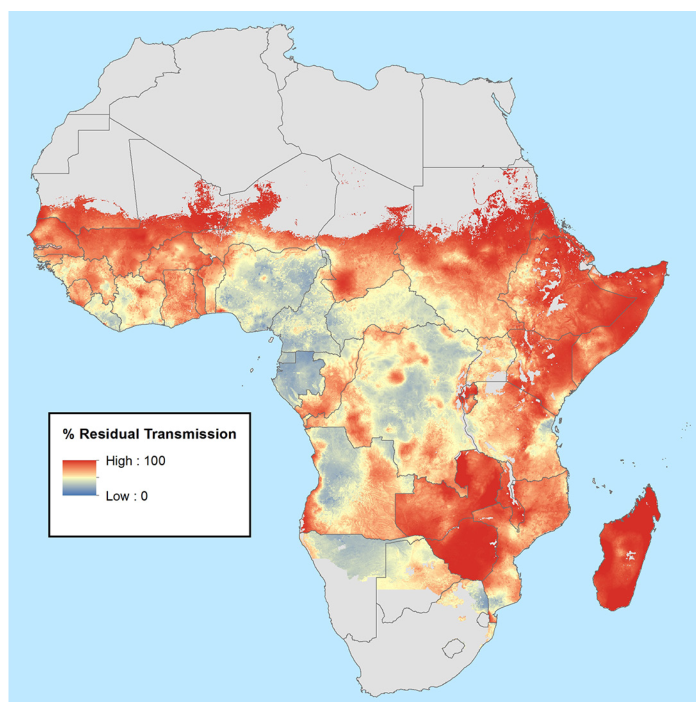
It was predicted that increasing and sustaining ITN coverage at the likely maximum 80% level would yield substantial further decreases in transmission in Africa. However, this scenario also revealed that residual transmission would persist in nearly all locations, and in extended areas of West Africa, the Democratic Republic of Congo (DRC), and Mozambique this residual transmission would likely remain at relatively high levels (see Figures 2C and 3).

While some countries can achieve further gains by scaling ITN coverage to 80%, many countries that have already achieved high levels of coverage (such as Zimbabwe and Madagascar) are at a point where the proportion of current transmission that is residual is very high (Figure 4).

Novel Vector Control Approaches Are Necessary to Achieve Elimination and Eradication

- Significant residual transmission would exist in Africa even if ITNs were maintained at a likely maximum feasible level of 80% coverage;
- New vector control approaches will likely be vital to achieve the further reductions necessary as part of elimination efforts; and
- A combination of background factors combine to mediate ITN effectiveness, and hence levels of residual transmission, in different locations, and so new tools should be appropriately designed and targeted based on local settings.

Figure 4. Predicted proportion of remaining transmission in 2015 that is due to residual transmission



Next Frontier in Geospatial Analytics of Malaria: Understand Residual Transmission Globally and at Subnational Level

- Expanding the analysis to the remainder of the malaria endemic world, and encompassing *P. vivax*, would advance our understanding of residual transmission. Residual transmission may be an even greater challenge outside Africa, especially in parts of Asia where mosquito vectors favoring outdoor and daytime biting are predominant.
- Going beyond this continental-scale analysis to better understand the precise nature of this transmission (where, why, by which vector, on which humans) at national and sub-national levels should be a priority moving forward.
- The analyses presented here can (i) inform the design of more localized, prospectively designed studies to elucidate these factors further; and (ii) provide an analytical framework which can be further informed by the detailed insights anticipated from future research, allowing findings to be scaled-up to their continental or global policy context.

References

1. World Health Organization. Control of residual malaria parasite transmission: Guidance note, September 2014, Geneva: WHO; 2014. Available from: http://www.who.int/malaria/publications/atoz/technical-note-control-of-residual-malaria-parasite-transmission-sep14.pdf.
2. Bhatt S, Weiss DJ, Mappin B, et al. Coverage and system efficiencies of insecticide-treated nets in Africa from 2000 to 2017. eLife 2015; 4.
3. Durnez L, Coosemans M. Residual Transmission of Malaria: An Old Issue for New Approaches. Anopheles mosquitoes - New insights into malaria vectors: InTech; 2013: 671–704

UCSF Global Health Sciences Global Health Group

map malaria atlas project

The Parker Foundation