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Simulating Malaria Evolution and Impact of Antimalarial Drug Deployment in Burkina Faso Using a Newly Calibrated Individual-Based Model

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Abstract

With over 8 million annual cases reported throughout the entire country, Plasmodium falciparum malaria presents a serious health burden in Burkina Faso. As in every malaria-endemic country, this public health challenge requires sustained attention to reduce the number of deaths and curb possible emergence of drug resistance mutations. To help with decision making on drug-resistance preparation, we simulated malaria transmission and evolution across Burkina Faso using a previously validated individual-based mathematical simulation model. The model was calibrated using 2022 prevalence data from the Malaria Atlas Project, 2024 incidence data from the 75 health districts in Burkina Faso, known seasonal transmission patterns, and drug choice and coverage data from demographic health surveys. We evaluated multiple antimalarial drug deployment strategies, between 2026 and 2035, to evaluate which ones would have the largest preventive effect on delaying the arrival of artemisinin-resistant falciparum genotypes. We evaluated geographic strategies where different artemisinin combination therapies (ACTs) are distributed to different districts, multiple first-line therapy (MFT) approaches, and drug rotation approaches. Our results indicate that certain MFT and rotation strategies, when implemented with high deployment efficiency, have potential to reduce treatment failure rates by 10% to 25% compared to the status quo. Geographically stratified approaches have similar effects at reducing treatment failures but only if accompanied by rotations. These results highlight the importance of preparing for the arrival of artemisinin-resistant genotypes for countries where artemisinin resistance has not yet been detected.

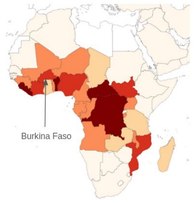
Background

Malaria

- life-threatening vector-borne disease killing approximately **600,000** people worldwide (3rd largest cause of infectious disease mortality)
- poses important global health challenge particularly in Africa
- The wide success of Artemisinin Combination Therapy (ACTs) is threatened by emergence of partial artemisinin resistance (ART-R)
- Primary Strategy is deployment of multiple first-line therapies (MFTs) which needs to be customly tailored for each country.

Malaria in Burkina Faso

- Landlocked country in West-Africa
- Population : **23.02 million** (2023)
- Malaria Cases : **8.1 million** (3.2% of global) (2023)
- Deaths : **16000** (2.7% of global) (2023) (World Malaria Report[2])
- endemic throughout the country
- strong seasonality with upsurge around October
- pfpr : 23.12 per 100 children (2022) (Malaria Atlas Project)[1]
- incidence rate : 289.84 per 1000 people per year (2022)
- One of the '*High Burden, High Impact*' countries as classified by World Health Organization (WHO)
- No detection of *pfkelch13* ART-R mutants yet

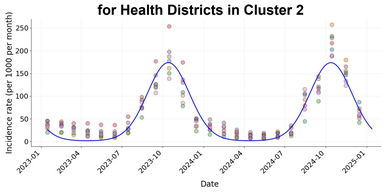


Nearly 95% of malaria cases are concentrated in sub-Saharan Africa. The figure above which shows Malaria prevalence in different African Countries including Burkina Faso (darker color denotes higher prevalence). The figure is reproduced from Malaria Atlas Project[1])

Seasonality

We extracted seasonality patterns using health district-wise monthly incidence data from 2023 and 2024. Health districts were first clustered using k-means clustering algorithm based on their incidence rate pattern, and a representative seasonal curve was fitted for each cluster to capture the underlying seasonality.

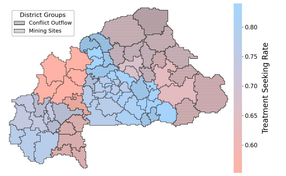
Cosine Seasonal Fit to Malaria Incidence for Health Districts in Cluster 2



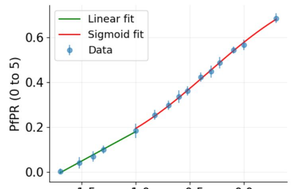
The figure on the left shows a scatter plot of incidence rates for five health districts belonging to cluster 2,. Points of the same color represent data from the same health district, while the blue curve shows the fitted seasonal trend. From this curve, a seasonality multiplier can be derived for each day of the year. Similar seasonal patterns were obtained for the remaining four clusters.

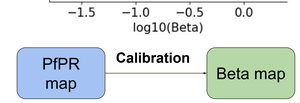
Calibration

- **Region-wise configuration** : Treatment distribution set as 85% public and 15% private sector; public sector uses 90% AL and 10% DHAPPQ, while private sector proportions vary regionally based on DHS data.
- **Population binning** : Pixels within each health district are assigned to population bins using Jenks' natural breaks algorithm.
- **Input generation** : Input files created for each (population bin, region, cluster, treatment access) combination, totaling 391 configurations with 20 beta values each (117,600 simulations; 7,840 input files).
- **Simulation execution** : Single-pixel simulations were run on a high-performance computing (HPC) cluster.
- **Curve Fitting** : For each configuration, PfPR values are plotted against corresponding beta values, and a piecewise linear+sigmoid curve was fitted to capture their relationship. The figure on right shows plot of one particular configuration
- **Beta assignment** : Pixel-wise PfPR data from the Malaria Atlas Project (2022) are used to assign each pixel a beta value through inverse mapping from fitted sigmoid curves.



The figure above shows treatment access across Burkina Faso's health districts. The figure below shows the beta-PfPR curve for one of 391 configurations; each configuration has its own curve, and every pixel's beta is drawn from one of them.

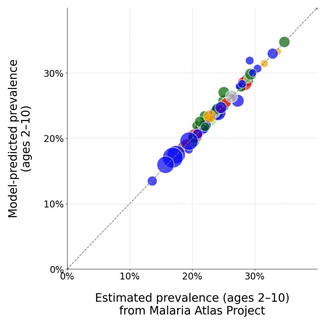




Validation

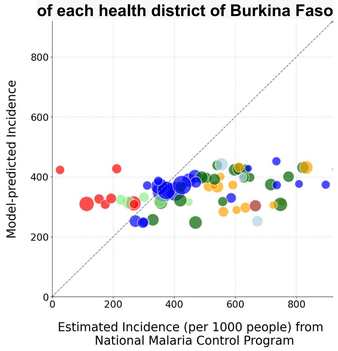
- Simulations[3] for the whole country with human movements[4] were run using the calibrated beta values to ensure model is **well-calibrated.**

True Prevalence vs Predicted Prevalence of each health district of Burkina Faso



Model-reported countrywide PfPR in 2022 **23.11**
MAP-reported countrywide PfPR in 2022 **23.12**
Model-reported Total Public Sector cases in 2023 **8,213,191**
Total cases according to World Malaria Report in 2023 **8,139,355**

True Incidence vs Predicted Incidence of each health district of Burkina Faso



Model results are the median of 20 simulations. In top figure, model-reported prevalence of all health districts match prevalence from Malaria Atlas Project (pixel level prevalence are aggregated to district level). Red circles correspond to districts where residents are leaving due to conflict, arriving in districts marked by green circles. Orange circles correspond to district with large population influx due to recent increases in mining activity. **Blue circles correspond to district unaffected by conflict or mining**; several districts (additional colors) are affected by both. In figure on right, incidence of highly populated unaffected districts are correctly reported by model.

Intervention Studies

37 distinct strategies were evaluated, grouped into five categories as follows :

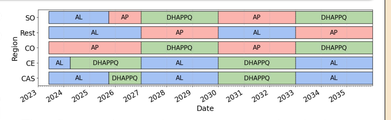
Status Quo (Geo-MFT): AP is deployed in Centre Ouest, DHAPPQ in Centre Est, and AL in rest of the country. ACTs do not rotate. *(1 strategy)*

Single First Line Therapies (SFTs) : Whole country switches to AL, ASAQ, AP, or DHAPPQ. *(4 strategies)*

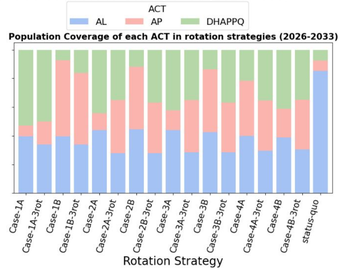
Multiple First Line Therapies (MFTs) : Different proportions of AL, DHAPPQ and AP were considered. *(10 strategies)*

Geographic MFT with rotation: Different groups of regions are assigned different ACTs, which rotate every 3 years. Eight "2 ACT per region" strategies are proposed by NMCP, which are augmented with corresponding "3 ACT per region" strategies. *(16 strategies)*

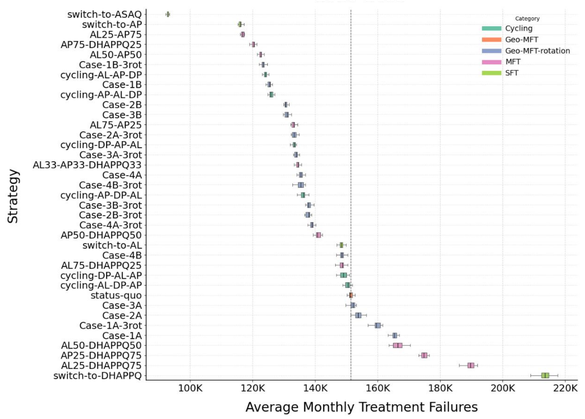
Cycling : Entire country switches to a new ACT every 3 years. Different cycling orders were considered. (6 strategies)



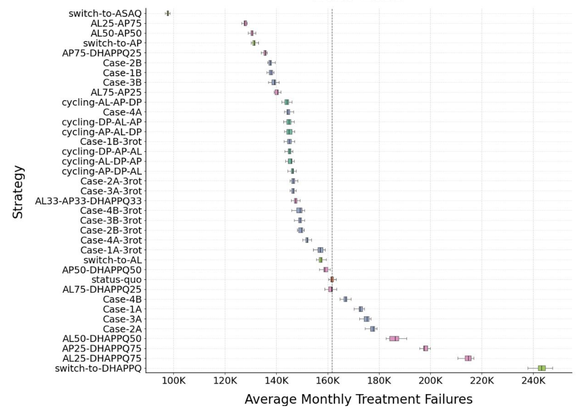
*The figure above shows an example deployment timeline of one of the proposed "geographic MFT with rotation" strategies (Case-2B). Starting in 2026, **Sud-Ouest (SO)** and **Centre-Ouest (CO)** alternate between **AP** and **DHAPPQ**, **Centre-Est (CE)** and **Cascades (CAS)** alternate between **DHAPPQ** and **AL**, while all other regions **(Rest)** rotate between **AL** and **AP**. The figure below shows the proportion of people covered by each ACT for all rotation strategies considered in the forecast period (2026-2033)*



2026-2033

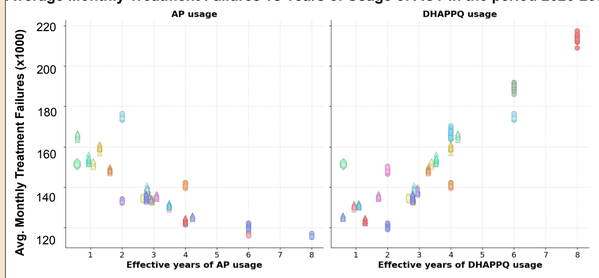


2026-2035



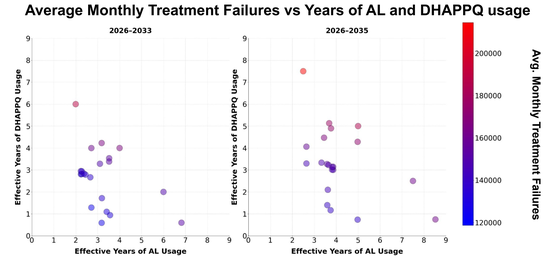
We evaluated different drug deployment strategies in terms of average monthly treatment failures across 8 years (2026-2033) and 10 years (2026-2035) horizons . Switch to ASAQ performs the best while switch to DHAPPQ performs the worst. "1B", "2B", "3B", and "4A" all come out as quite good approaches because they limit the use of DHA-PPQ to fewer regions and shorter periods. In general, more ACTs per location is better for the long-term.

Average Monthly Treatment Failures vs Years of Usage of ACT in the period 2026-2033



Each point in the figure above corresponds to a strategy with shape denoting strategy category. Increased AP usage, over an 8-year period, generally leads to fewer treatment failures.Increased DHA-PPQ usage, generally leads to increased treatment failures counts over 8 years, but if DHA-PPQ usage is below ~30% of all usage then treatment failure counts seem to remain low.

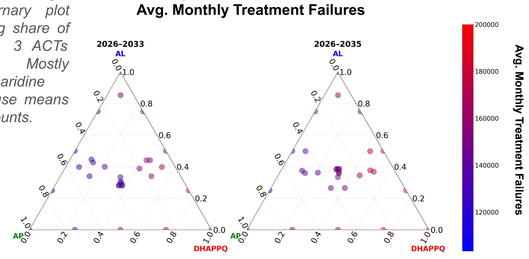
Average Monthly Treatment Failures vs Years of AL and DHAPPQ usage



The figure above shows less AL use and less DHA-PPQ means fewer treatment failures (TF) as indicated by circles with bluish tint.

The figure on right is a ternary plot visualizing share of each of 3 ACTs together. Mostly AS-Pyronaridine and AL use means low TF counts.

Ternary Plots of ACT Proportions vs Avg. Monthly Treatment Failures



Future Works

- Adjustment of beta values for some health districts to improve incidence calibration
- Implementation and analysis of **Seasonal Malaria Chemoprevention (SMC)** . The framework can be used to evaluate resistance impacts of SMC in other African countries as well.
- Evaluation of **Age Based Distribution of ACTs as MFTs** using different criteria for determining optimal age brackets

References

1. Weiss DJ, Lucas TCD, Nguyen M, Nandi AK, Bisanzio D, Battle KE, et al. Mapping the global prevalence, incidence, and mortality of Plasmodium falciparum, 2000–17: a spatial and temporal modelling study. The Lancet. 2019 Jul 27; 394(10195):322–31.
2. Venkatesan P. WHO world malaria report 2024. The Lancet Microbe. 2025 Apr 1;6(4):101073. doi: 10.1016/j.lanmic.2025.101073.
3. Nguyen TD, Olliaro P, Dondorp AM, Baird JK, Lam HM, Farrar J, et al. Optimum population-level use of artemisinin combination therapies: a modelling study. Lancet Glob Health. 2015 Dec 1; 3(12):e758–66. https://doi.org/10.1016/S2214-109X(15)00162-X PMID: 26545449
4. Zupko, R.J., Nguyen, T.D., Wesolowski, A. et al. National-scale simulation of human movement in a spatially coupled individual-based model of malaria in Burkina Faso. *Sci Rep* **13**, 321 (2023). https://doi.org/10.1038/s41598-022-26878-5
5. Zupko RJ, Nguyen TD, Somé AF, Tran TN, Gerardin J, Dudas P, Giang DDH, Tran KT, Wesolowski A, Ouédraogo JB, Boni MF. Long-term effects of increased adoption of artemisinin combination therapies in Burkina Faso. PLOS Glob Public Health. 2022 Feb 2;2(2):e0000111. doi: 10.1371/journal.pgph.0000111. PMID: 36962300; PMCID: PMC10021447.

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