How many nets are needed to reach universal coverage – an update

# Author list

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# Abstract

* To be written last (350 words)

Keywords (3-10)

# Background

Insecticide treated nets (ITNs) have served as the cornerstone of malaria vector control for the past two decades. Over 2.5 billion ITNs have been delivered to countries [1], primarily through periodic mass distribution campaigns scheduled at three-year intervals, aligning with the expected lifespan of nets. Recent work has shown significant variation in ITN durability across geographic zones, and while some studies support a three-year median lifespan, multi-country analyses of ITN retention times indicate half of countries can expect two years or less of useful life for the majority of nets they distribute [2]. The implications of shorter-than-expected retention times have important implications for the ways in countries quantify ITNs for mass campaigns, and raise several key questions. First, what is the projected impact of the mismatch in campaign cycle and ITN retention in terms of overall ITN coverage? Second, if mass campaigns every three years are insufficient due to ITNs lasting only 1-2 years, is switching to a two-year campaign cycle indicated, or are there alternative ways to distribute ITNs to ensure high rates of ITN access are maintained over time? Third, with what we know now about ITN retention and ITN distribution modalities, is population divided by 1.8 the correct quantification approach for mass campaigns for all countries? Finally, what would optimum ITN quantification look like for countries given their particular ITN retention times, aiming to sustain high levels of ITN access (the necessary, but not sufficient, precursor to ITN use)?

This paper explores these questions using a stock and flow model to project population ITN access for countries in sub-Saharan Africa over five different distribution scenarios, using estimated ITN retention times from Bertozzi-Villa et al [2] and varying quantification approaches within each distribution scenario.

# Methods

**Projections of future coverage**

Each country was assigned an indicative population of 10 million people in the database, starting in 2020, and an annual population growth rate of 3%, as the model outputs are adjusted for population and thus do not require specific population estimates.

ITNs were distributed in the model for each scenario as shown in Table 1.

Table 1: Distribution Scenarios and their ITN inputs

|  |  |  |  |
| --- | --- | --- | --- |
| Scenario | Mass Campaign | ANC/EPI (routine) | Annual school/ community |
| 1. “Status Quo” | In 2022, 2025, 2028, 2031, 2034 at population / 1.8 | 2020-2035, varying from 5-7% of the population | none |
| 1. “Full-scale continuous” | In 2020, to establish high coverage at population / 1.8 | 2021-2035 at 6% of the population | 2022-2032 varying from 1-20% of the population |
| 1. “Mass plus continuous” | In 2022, 2025, 2028, 2031, 2034 at population / 1.8 | 2020-2035 at 6% of the population | Only in years between campaigns, varying from 1-20% of the population |
| 1. “Varying 3-year mass” | In 2022, 2025, 2028, 2031, 2034, varying from population / 1.0-2.0 | 2020-2035 at 6% of the population | none |
| 1. “Varying 2-year mass” | In 2022, 2024, 2026, 2028, 2030, 2032, 2034 varying from population / 1.0-2.0 | 2020-2035 at 6% of the population | none |

For each year, the stock and flow model used a country-specific estimated median lifespan from Bertozzi-Villa et al [2] to decay each crop of distributed nets annually. The net decay functions rely on smooth-compact loss function developed by Nakul Chitnis and described in Koenker et al and Bhatt et al [3,4], and are shown in Figure 1.

Figure 1: A) ITN retention times B) Smooth-compact loss function with Tanzania as an example C) Access-NPC relationship 2020 from Bertozzi-Villa et al D) nonparametric conditional quartile function for ITN access as a bunfction of NPC

|  |  |
| --- | --- |
|  | Chart  Description automatically generated |
|  | Points are regions |

The total net crop (consisting of all surviving nets from various channels to date) was summed for each year and country. This was then divided by the population projected to calculate nets-per-capita (NPC) in each year and council.

To estimate ITN access from NPC, a nonparametric conditional quartile function for ITN access as a function of NPC was estimated from 124 demographic health survey data and malaria indicator surveys (MIS). A grid of 100 points was produced and used to predict ITN access from NPC (Figure 1). Confidence intervals for both estimated median lifespan and the function of ITN access vs NPC were used to generate an overall confidence interval around the estimate of ITN access.

To further understand the relative sizes of ITN distributions through various channels, total ITNs delivered per channel were divided by the population and expressed as “nets issued as a percentage of the population” (NPP).

**Scenarios**

To inform recommendations for quantification of ITNs for the annual SNP, the above process was used to model ITN distributions under five typical ITN distribution scenarios, varying quantification approaches within each scenario:

1. “Status Quo”: Mass campaigns every three years with routine distribution of ITNs to pregnant women and infants through antenatal clinics (ANC) and immunization visits (EPI). Quantification of the mass campaigns was fixed at population / 1.8 while quantification of routine distribution varied from population x 5%-7%.
2. “Full-scale continuous”: Full-scale annual school distribution of ITNs with routine distribution of ANC and EPI ITNs, fixing the routine distribution at population x 6% and varying the quantification of school distributions from population x 1-20%
3. “Mass plus continuous”: Mass campaign every three years with routine distribution of ANC and EPI ITNs and with annual school distribution in a limited number of classes, or limited community distribution in the years between campaigns. Quantification of the mass campaigns was fixed at population / 1.8 and routine distribution at population x 6%, varying the annual school/community distribution between population x 7-25%.
4. “Varying 3-year mass”: Mass campaigns every three years with routine distribution of ITNs to pregnant women and infants through antenatal clinics (ANC) and immunization visits (EPI). Quantification of routine distribution was fixed at 6%, and quantification of the mass campaigns was varied from population / 1.0 to population / 2.0 in increments of 0.1.
5. “Varying 2-year mass”: Mass campaigns every two years with routine distribution of ITNs to pregnant women and infants through antenatal clinics (ANC) and immunization visits (EPI). Quantification of routine distribution was fixed at 6%, and quantification of the mass campaigns was varied from population / 1.0 to population / 2.0 in increments of 0.1.

All scenarios with mass campaigns began with a mass campaign in 2022 and ended in 2035. The “full scale continuous” scenario assumed a mass campaign (quantified with population / 1.8) in 2020 to scale up coverage prior to switching over to a fully continuous ITN strategy.

# Results

Given a target of 80% ITN access, the recommended quantification approaches for each scenario varied considerably across countries, driven primarily by the median retention time. Recommended quantification approaches are summarized for the scenarios that include continuous distribution in Table 2, for 3-year mass campaigns in Table 3, and for 2-year mass campaigns in Table 4.

Table : Recommended annual quantifiers for scenarios involving continuous distribution. For example, Angola would need to distribution ITNs equivalent to 25% of the population on an annual basis in order maintain ITN access at a 70% target. To maintain ITN access at an 80% target, ITN quantification for continuous distribution would need to be population x 30% on an annual basis. Given Angola’s estimated net decay rate, it is not feasible to maintain ITN access at 90%, assuming quantification rates for annual continuous distribution are capped at 30% of the population.

| Minimum annual quantifier for continuous distribution channels to sustain ITN access at targets of 70, 80, and 90% | | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| Country Code | Scenario 2 (full continuous strategy) | | | Scenario 3 (continuous between mass campaigns) | | |
| 70% | 80% | 90% | 70% | 80% | 90% |
| AO | 25 | 30 |  | 23 | 29 |  |
| BF | 19 | 25 |  | 11 | 17 | 28 |
| BI | 23 | 29 |  | 17 | 23 | 26 |
| BJ | 26 |  |  | 23 | 30 |  |
| CD | 22 | 28 |  | 15 | 21 | 28 |
| CF | 15 | 24 | 28 | 7 | 10 | 22 |
| CG | 9 | 12 | 20 | 7 | 7 | 11 |
| CI | 19 | 29 | 30 | 9 | 14 | 26 |
| CM | 7 | 10 | 17 | 7 | 7 | 7 |
| DJ | 26 |  |  | 24 | 21 |  |
| ER | 9 | 12 | 20 | 7 | 7 | 10 |
| ET | 23 | 29 |  | 17 | 23 | 30 |
| GA | 7 | 10 | 17 | 7 | 7 | 8 |
| GH | 17 | 27 | 29 | 8 | 7 | 24 |
| GM | 21 | 25 |  | 11 | 16 | 27 |
| GN | 20 | 26 |  | 13 | 19 | 30 |
| GQ | 7 | 10 | 16 | 7 |  | 7 |
| GW | 22 | 28 |  | 16 | 22 | 29 |
| KE | 12 | 17 | 27 | 7 | 7 | 15 |
| KM | 13 | 19 | 28 | 7 | 8 | 16 |
| LR | 26 |  |  | 25 | 22 |  |
| MG | 20 | 24 | 30 | 10 | 15 | 27 |
| ML | 9 | 12 | 21 | 7 | 7 | 7 |
| MR | 26 |  |  | 23 | 30 |  |
| MW | 23 | 29 |  | 17 | 23 | 30 |
| MZ | 22 | 28 |  | 17 | 23 | 30 |
| NE | 7 | 10 | 17 | 7 | 7 | 7 |
| NG | 12 | 18 | 27 | 7 | 7 | 15 |
| RW | 21 | 25 |  | 11 | 17 | 28 |
| SD | 9 | 12 | 20 | 7 | 7 | 11 |
| SL | 21 | 27 |  | 14 | 20 | 30 |
| SN | 22 | 28 |  | 16 | 22 | 30 |
| SO | 12 | 16 | 26 | 7 | 7 | 14 |
| SS | 27 |  |  | 25 | 22 |  |
| TD | 26 |  |  | 25 | 22 |  |
| TG | 11 | 15 | 25 | 7 | 7 | 13 |
| TZ | 13 | 19 | 28 | 7 | 8 | 16 |
| UG | 20 | 24 | 30 | 10 | 15 | 26 |
| ZM | 23 | 29 |  | 17 | 23 | 30 |
| ZW | 9 | 12 | 21 | 7 | 7 | 7 |

Table : Lowest level of ITN access between 3-year campaigns at different population quantifiers. For example, with the standard quantifier of population / 1.8, Burkina Faso reaches a low point of 45% ITN access between campaigns. Using population / 1.1 would result in an estimated low point of 61% population ITN access between campaigns. Routine ITN delivery to pregnant women and infants is included.

| Lowest ITN access between 3-year campaigns for each quantifier | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Cty | Population divided by | | | | | | | | | | |
| 1.0 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2.0 |
| AO | 29 | 27 | 26 | 26 | 24 | 24 | 24 | 23 | 23 | 23 | 23 |
| BF | 64 | 61 | 58 | 55 | 52 | 51 | 49 | 46 | 45 | 45 | 43 |
| BI | 43 | 42 | 39 | 38 | 36 | 36 | 35 | 33 | 33 | 32 | 32 |
| BJ | 26 | 26 | 24 | 24 | 23 | 23 | 23 | 23 | 21 | 21 | 21 |
| CD | 52 | 49 | 46 | 45 | 42 | 41 | 41 | 39 | 38 | 36 | 36 |
| CF | 80 | 76 | 73 | 70 | 68 | 65 | 63 | 61 | 59 | 56 | 55 |
| CG | 95 | 92 | 89 | 87 | 85 | 84 | 82 | 81 | 79 | 77 | 76 |
| CI | 70 | 66 | 64 | 61 | 58 | 56 | 54 | 52 | 51 | 49 | 48 |
| CM | 100 | 96 | 93 | 91 | 89 | 87 | 86 | 84 | 82 | 81 | 80 |
| DJ | 24 | 24 | 23 | 23 | 23 | 21 | 21 | 21 | 21 | 21 | 20 |
| ER | 96 | 93 | 90 | 88 | 86 | 84 | 83 | 81 | 80 | 79 | 77 |
| ET | 45 | 43 | 41 | 39 | 38 | 36 | 36 | 35 | 33 | 33 | 32 |
| GA | 99 | 95 | 93 | 90 | 88 | 86 | 85 | 83 | 82 | 81 | 80 |
| GH | 75 | 71 | 68 | 65 | 63 | 61 | 58 | 56 | 54 | 52 | 51 |
| GM | 66 | 63 | 61 | 58 | 55 | 52 | 51 | 49 | 48 | 46 | 45 |
| GN | 59 | 56 | 54 | 51 | 49 | 46 | 45 | 43 | 42 | 41 | 41 |
| GQ | 100 | 97 | 94 | 92 | 89 | 88 | 86 | 85 | 83 | 82 | 81 |
| GW | 49 | 46 | 45 | 42 | 41 | 39 | 38 | 38 | 36 | 35 | 35 |
| KE | 87 | 84 | 82 | 80 | 78 | 75 | 73 | 71 | 69 | 66 | 65 |
| KM | 85 | 82 | 80 | 77 | 74 | 72 | 70 | 68 | 65 | 64 | 62 |
| LR | 24 | 23 | 23 | 21 | 21 | 21 | 21 | 20 | 20 | 20 | 20 |
| MG | 69 | 64 | 62 | 59 | 56 | 54 | 52 | 51 | 49 | 48 | 46 |
| ML | 94 | 91 | 89 | 86 | 85 | 83 | 81 | 80 | 78 | 76 | 74 |
| MR | 26 | 26 | 24 | 24 | 23 | 23 | 23 | 23 | 21 | 21 | 21 |
| MW | 45 | 43 | 41 | 39 | 38 | 36 | 36 | 35 | 33 | 33 | 32 |
| MZ | 46 | 43 | 42 | 41 | 39 | 38 | 36 | 35 | 35 | 33 | 33 |
| NE | 100 | 96 | 93 | 91 | 89 | 87 | 86 | 84 | 82 | 81 | 80 |
| NG | 86 | 84 | 81 | 80 | 77 | 74 | 72 | 70 | 68 | 66 | 64 |
| RW | 64 | 62 | 58 | 55 | 54 | 51 | 49 | 48 | 46 | 45 | 43 |
| SD | 95 | 92 | 89 | 87 | 85 | 84 | 82 | 81 | 79 | 77 | 76 |
| SL | 56 | 54 | 51 | 48 | 46 | 45 | 43 | 42 | 41 | 39 | 39 |
| SN | 48 | 45 | 42 | 41 | 39 | 38 | 36 | 36 | 35 | 33 | 33 |
| SO | 88 | 86 | 84 | 81 | 80 | 77 | 75 | 73 | 71 | 69 | 68 |
| SS | 23 | 23 | 21 | 21 | 21 | 21 | 20 | 20 | 20 | 20 | 20 |
| TD | 24 | 23 | 23 | 21 | 21 | 21 | 21 | 20 | 20 | 20 | 20 |
| TG | 89 | 87 | 84 | 82 | 80 | 79 | 76 | 74 | 72 | 70 | 69 |
| TZ | 85 | 82 | 80 | 78 | 75 | 72 | 70 | 68 | 66 | 64 | 63 |
| UG | 69 | 65 | 62 | 59 | 56 | 55 | 52 | 51 | 49 | 48 | 46 |
| ZM | 45 | 42 | 41 | 39 | 38 | 36 | 35 | 35 | 33 | 32 | 32 |
| ZW | 94 | 91 | 88 | 86 | 84 | 82 | 81 | 80 | 78 | 76 | 74 |

Table : Lowest level of ITN access between 2-year campaigns at different population quantifiers. For example, with the standard quantifier of population / 1.8, Burkina Faso reaches a low point of 79% ITN access in the year between campaigns. Using population / 1.2 would result in an estimated low point of 91% population ITN access between campaigns. Values of 100 indicate excess nets in the system (for example Cameroon). Routine ITN delivery to pregnant women and infants is included.

| Lowest ITN access between 2-year campaigns for each quantifier | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Cty | Population divided by | | | | | | | | | | |
| 1.0 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2.0 |
| AO | 84 | 81 | 78 | 74 | 71 | 68 | 65 | 63 | 61 | 59 | 56 |
| BF | 97 | 94 | 91 | 88 | 86 | 84 | 82 | 81 | 79 | 77 | 75 |
| BI | 90 | 87 | 84 | 82 | 80 | 77 | 75 | 72 | 70 | 68 | 65 |
| BJ | 82 | 80 | 76 | 73 | 70 | 66 | 64 | 62 | 59 | 58 | 55 |
| CD | 93 | 90 | 87 | 85 | 82 | 80 | 78 | 76 | 73 | 71 | 69 |
| CF | 100 | 100 | 98 | 95 | 92 | 90 | 88 | 86 | 85 | 83 | 82 |
| CG | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 97 | 95 | 94 |
| CI | 100 | 97 | 93 | 91 | 88 | 86 | 84 | 82 | 81 | 80 | 78 |
| CM | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 98 |
| DJ | 81 | 79 | 75 | 71 | 69 | 65 | 63 | 61 | 58 | 56 | 54 |
| ER | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 98 | 96 | 94 |
| ET | 91 | 88 | 85 | 82 | 80 | 78 | 75 | 73 | 71 | 69 | 66 |
| GA | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 99 | 97 |
| GH | 100 | 99 | 95 | 93 | 90 | 88 | 86 | 84 | 82 | 81 | 80 |
| GM | 99 | 95 | 92 | 89 | 87 | 85 | 83 | 81 | 80 | 78 | 76 |
| GN | 96 | 92 | 89 | 87 | 85 | 82 | 81 | 79 | 77 | 74 | 72 |
| GQ | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 98 |
| GW | 92 | 89 | 86 | 84 | 81 | 80 | 77 | 75 | 72 | 70 | 68 |
| KE | 100 | 100 | 100 | 100 | 99 | 96 | 94 | 92 | 90 | 88 | 87 |
| KM | 100 | 100 | 100 | 100 | 97 | 94 | 92 | 90 | 88 | 87 | 85 |
| LR | 81 | 77 | 74 | 70 | 68 | 64 | 62 | 59 | 56 | 55 | 54 |
| MG | 99 | 96 | 92 | 90 | 87 | 86 | 84 | 82 | 80 | 79 | 77 |
| ML | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 99 | 96 | 95 | 93 |
| MR | 82 | 80 | 76 | 73 | 70 | 66 | 64 | 62 | 59 | 58 | 55 |
| MW | 91 | 88 | 85 | 82 | 80 | 78 | 75 | 73 | 71 | 69 | 66 |
| MZ | 91 | 88 | 85 | 83 | 81 | 79 | 76 | 73 | 71 | 69 | 66 |
| NE | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 98 |
| NG | 100 | 100 | 100 | 100 | 98 | 96 | 93 | 91 | 90 | 88 | 87 |
| RW | 98 | 94 | 91 | 88 | 86 | 84 | 82 | 81 | 79 | 77 | 75 |
| SD | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 97 | 95 | 94 |
| SL | 94 | 91 | 88 | 86 | 84 | 82 | 80 | 78 | 75 | 73 | 71 |
| SN | 91 | 88 | 85 | 83 | 81 | 79 | 76 | 74 | 71 | 69 | 68 |
| SO | 100 | 100 | 100 | 100 | 100 | 98 | 95 | 93 | 91 | 90 | 88 |
| SS | 80 | 77 | 73 | 70 | 66 | 64 | 62 | 59 | 56 | 55 | 52 |
| TD | 81 | 77 | 74 | 70 | 68 | 64 | 62 | 59 | 56 | 55 | 54 |
| TG | 100 | 100 | 100 | 100 | 100 | 99 | 96 | 94 | 92 | 90 | 89 |
| TZ | 100 | 100 | 100 | 100 | 97 | 95 | 92 | 90 | 89 | 87 | 86 |
| UG | 100 | 96 | 93 | 90 | 88 | 86 | 84 | 82 | 81 | 79 | 77 |
| ZM | 90 | 87 | 85 | 82 | 80 | 78 | 75 | 72 | 70 | 68 | 66 |
| ZW | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 98 | 96 | 94 | 93 |



* The complete set of graphs is included as Supplemental File 1.
* ANC-EPI variation not producing big differences
* Decay rates drive the quantification rates for each country
* Twoway quant factor NPP vs projected access – to illustrate what is needed more clearly? Faceted by strategy
* Areas suitable for school distribution based on enrolment and primary school classes, another map
* Or vs median lifespans…?
* ANC-EPI alone (7%) produces low access
* Approach 80% access when Cameroon at 15%; TZA requires 22%; Liberia at 25% is still only 60%
* X% of countries won’t reach 80% even at 25%....
* Ghana needs X and is only doing Y
* What is the lowest access we are willing to tolerate between campaigns, or at any time…?
* 2-year campaigns….?????
* Graph of current scenario to start, pop/1.8 with ANC at varying levels due to implementation (??)
* Then map of each country at its optimum and what quant factor that requires?
  + Graphs of three scenarios at varying levels of pop\*x%
* Comparability of projected estimates vs observed regional level survey data

# Discussion

* Based on projections into the future at varying levels of population\*x%, recommendations for continuous distribution quantification and universal coverage quantification in Tanzania
* Based on projections across multiple countries using varying ITN retention times from Bertozzi-Villa, overall recommendations for CD and campaign quantification for other countries
* Limitation of the methods
  + Parameter assumptions may vary by council – population, decay rates (behaviors; nets)
  + Missing data / how missing data was dealt with (proportional distribution among councils within a region)
  + Uncertainty of population estimates/projections

# Conclusion

# References

# Declarations

## Ethics approval and consent to participate

Not applicable

## Consent for publication

Not applicable

## Availability of data and materials

## Competing interests

## Funding

## Authors' contributions

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## Authors' information (optional)

# Supplementary information

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