Trends and projections of child immunization in 33 African countries (2000–2030): A spatial-temporal Bayesian analysis for Universal Health Coverage

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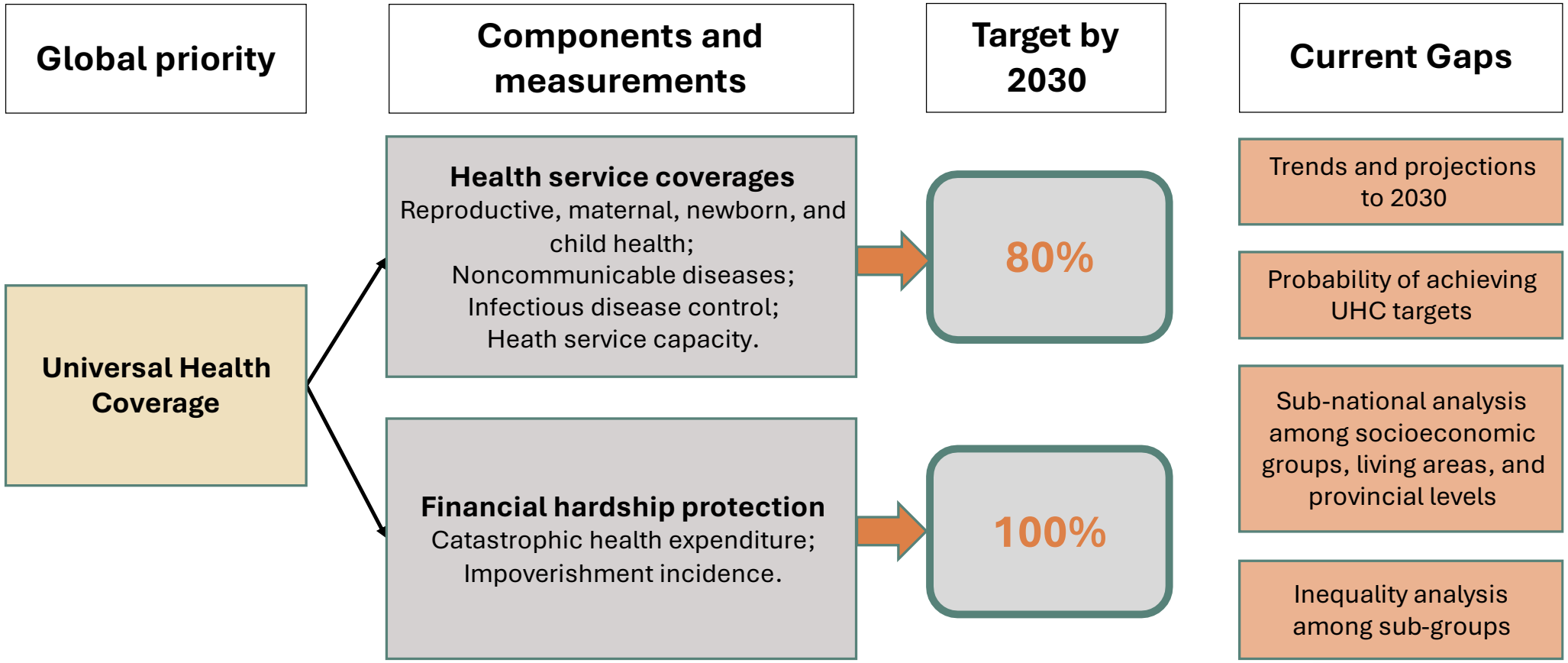
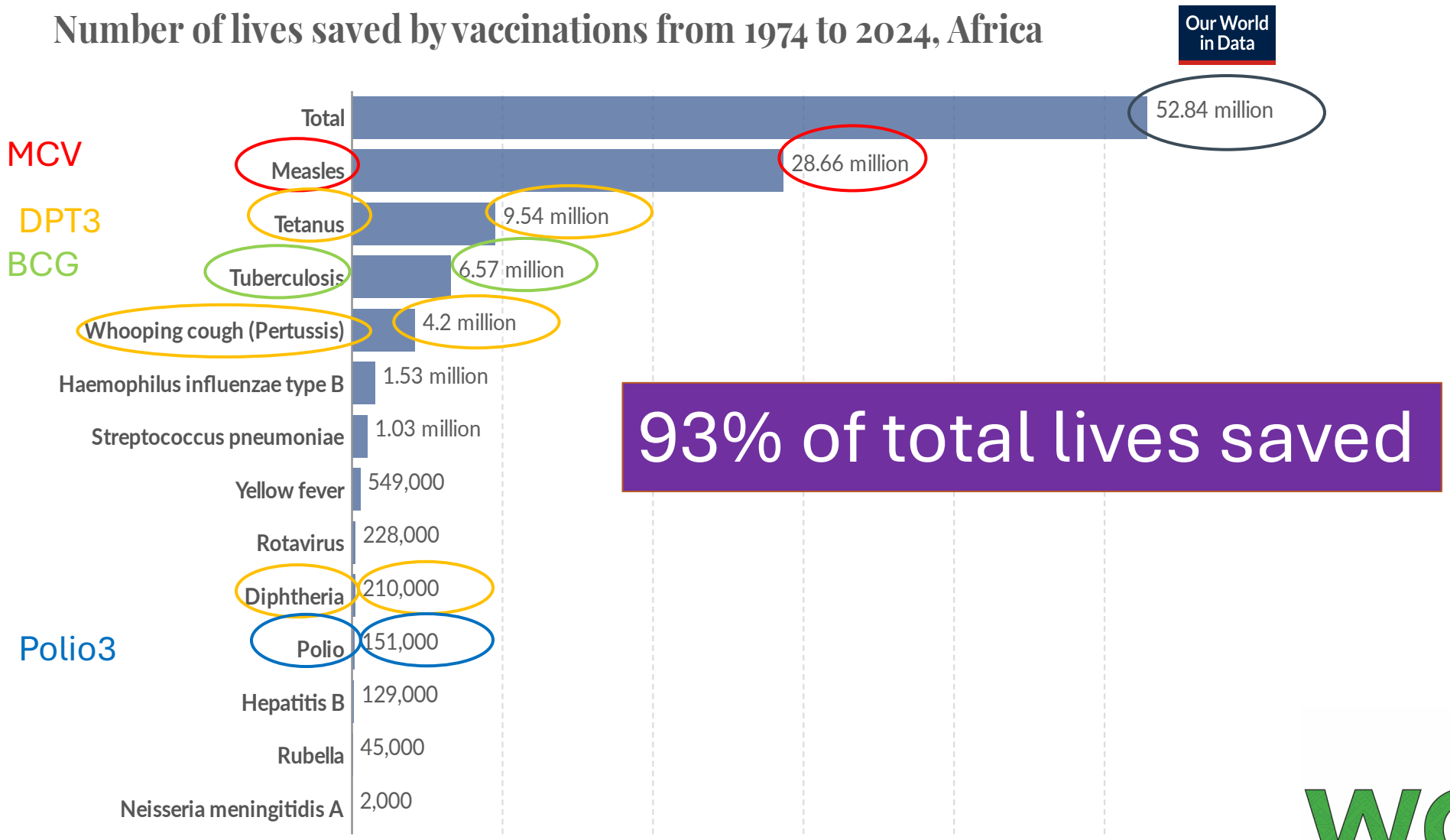
1. BACKGROUND

Universal Health Coverage framework



Child immunization in Africa



93% of total lives saved

Data source: Shattock et al. (2024). Contribution of vaccination to improved child survival: modelling 50 years of the Expanded Programme on Immunization.

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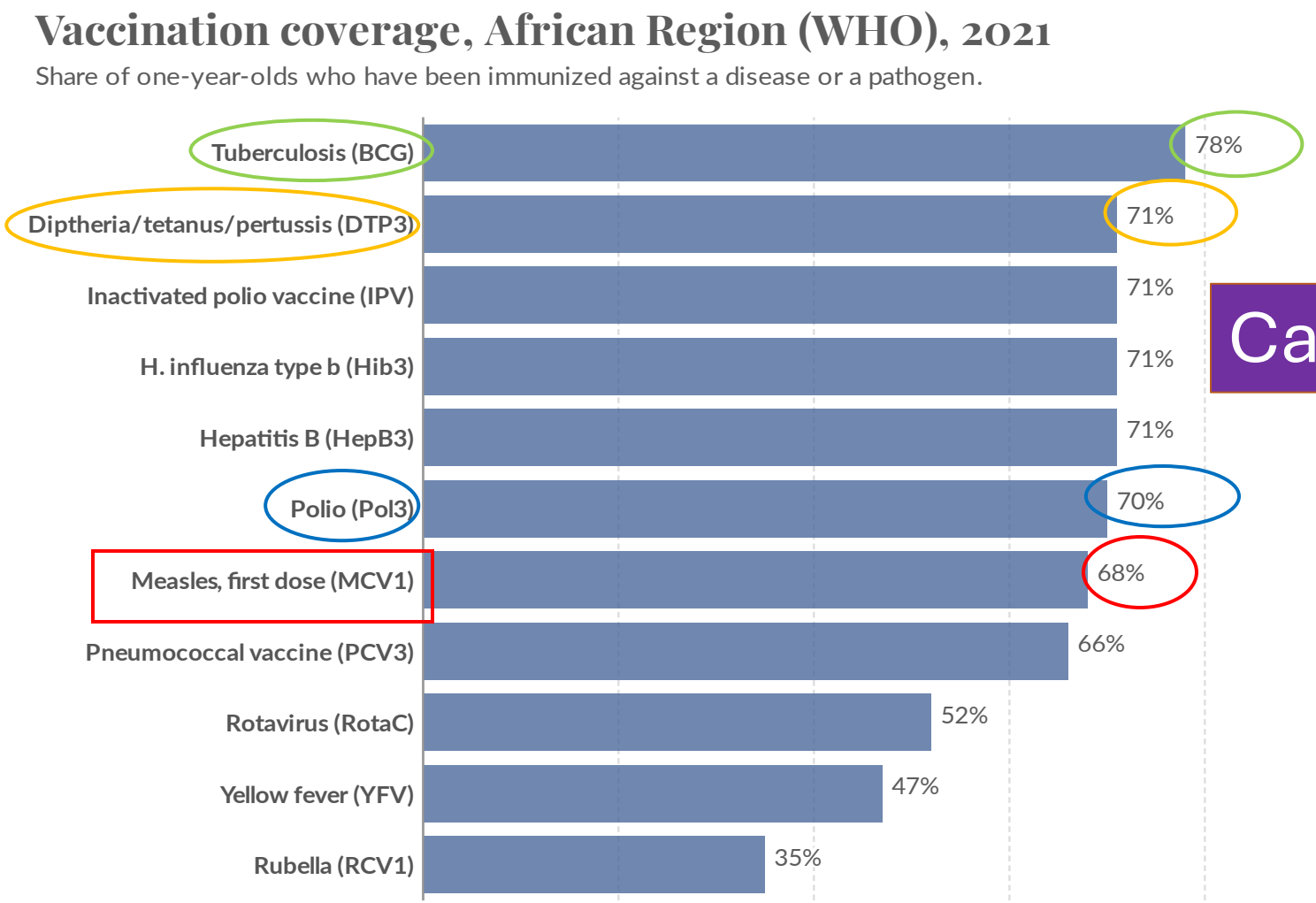
Current situation



Can achieve UHC target?

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Objectives

- To estimate the trends and make projections of child immunization coverage in African countries from 2000 to 2030, both at national and regional levels.
- To compute the probability of achieving global UHC targets.
- To investigate socioeconomic-related inequalities in child immunization coverage.

2. METHODS

Data sources

Year	Countries	Number of Survey	Records
2000	Egypt, Ethiopia, Malawi, Namibia, Rwanda	5	41,519
2001	Benin, Mali, Uganda, Zambia	4	28,195
2003	Burkina Faso, Egypt, Ghana, Kenya, Madagascar, Morocco, Mozambique, Nigeria	9	50,009
2004	Cameroon, Chad, Lesotho, Malawi, Tanzania	5	33,257
2005	Congo Brazzaville, Egypt, Ethiopia, Guinea, Rwanda, Senegal, Zimbabwe	8	55,162
2006	Benin, Eswatini, Mali, Namibia, Niger, Uganda	6	50,316
2007	Congo Democratic Republic, Liberia, Zambia	5	19,131
2008	Egypt, Ghana, Kenya, Madagascar, Nigeria, Rwanda	6	61,385
2009	Lesotho	1	3,606
2010	Burkina Faso, Burundi, Malawi, Rwanda, Senegal, Tanzania, Zimbabwe	8	72,148
2011	Benin, Cameroon, Congo Brazzaville, Cote d'Ivoire, Ethiopia, Mozambique, Uganda	10	67,817
2012	Guinea, Mali, Niger	3	27,588
2013	Congo Democratic Republic, Liberia, Namibia, Nigeria, Senegal, Togo, Zambia	9	90,005
2014	Chad, Egypt, Ghana, Kenya, Lesotho, Rwanda	6	68,528
2015	Angola, Senegal, Tanzania, Zimbabwe	4	42,158
2016	Burundi, Ethiopia, Malawi, South Africa, Uganda	6	57,063
2017	Benin, Senegal	2	24,253
2018	Cameroon, Guinea, Mali, Nigeria, Zambia	5	65,830
2019	Ethiopia	1	5,414

Demographic and Health Surveys (DHS)
33 African countries
863,384 records

Measurement of indicators

Indicators	Definitions	Recommended schedules
BCG immunization	The proportion of children aged 12-23 months who received one dose of BCG vaccine.	At birth
Measles	The proportion of children aged 12-23 months currently vaccinated against measles.	At 9 months
Polio3	The proportion of children aged 12-23 months who received three doses of polio vaccine.	Optional dose at birth, mandatory doses at 6, 10, and 14 weeks
DPT3	The proportion of children aged 12-23 months who received three doses of diphtheria, pertussis, and tetanus vaccine.	At 6, 10, and 14 weeks
Full immunization	The proportion of children aged 12-23 months who received three doses of DPT and Polio vaccines and one dose of BCG and measles vaccines	

Statistical analysis

Bayesian Spatial-Temporal Models

- Integrated Nested Laplace Approximation (INLA): Conducts approximate Bayesian inference within latent Gaussian models (Rue et al., 2009).
- Models Used: Besag-York-Mollié (BYM), and BYM2 (tailored parametrization for better interpretability).

Neighborhood Effects:

- Neighborhoods defined by areas shared boundaries, nationally or regionally.
- Uses Conditional Autoregressive (CAR) distribution to smooth data based on neighborhood structures.
- Assumed linear time trend in each area (Bernardinelli et al., 1995).

Random Slope Effects: between time and area.

Interaction Effects: between covariates and survey year.

Inclusion of nation's SDI (socio-demographic index)

Model Fitting:

- 900 models fitted using R-INLA.
- Model comparison using DIC (Deviance information criterion)

Statistical analysis (cont.)

Adjustments for complex survey design: Stratification, Clustering, and Sampling weights.

UHC Targets for Child Immunization Indicators: Exceedance Probabilities: Calculate P(pi > c), where pi is child vaccination coverage and c is the threshold value (0.8).

Measurement of socioeconomic-related inequalities:

- **Slope Index of Inequality (SII):** Quantifies absolute difference in percentage points.
- **Relative Index of Inequality (RII):** Quantifies relative ratio of coverages between most advantaged and disadvantaged sub-groups.

Changes in inequality over study period: Average Annual Rate of Change (AARC): Compute AARC and its 95% CrI using the formula provided and posterior predictive distribution.

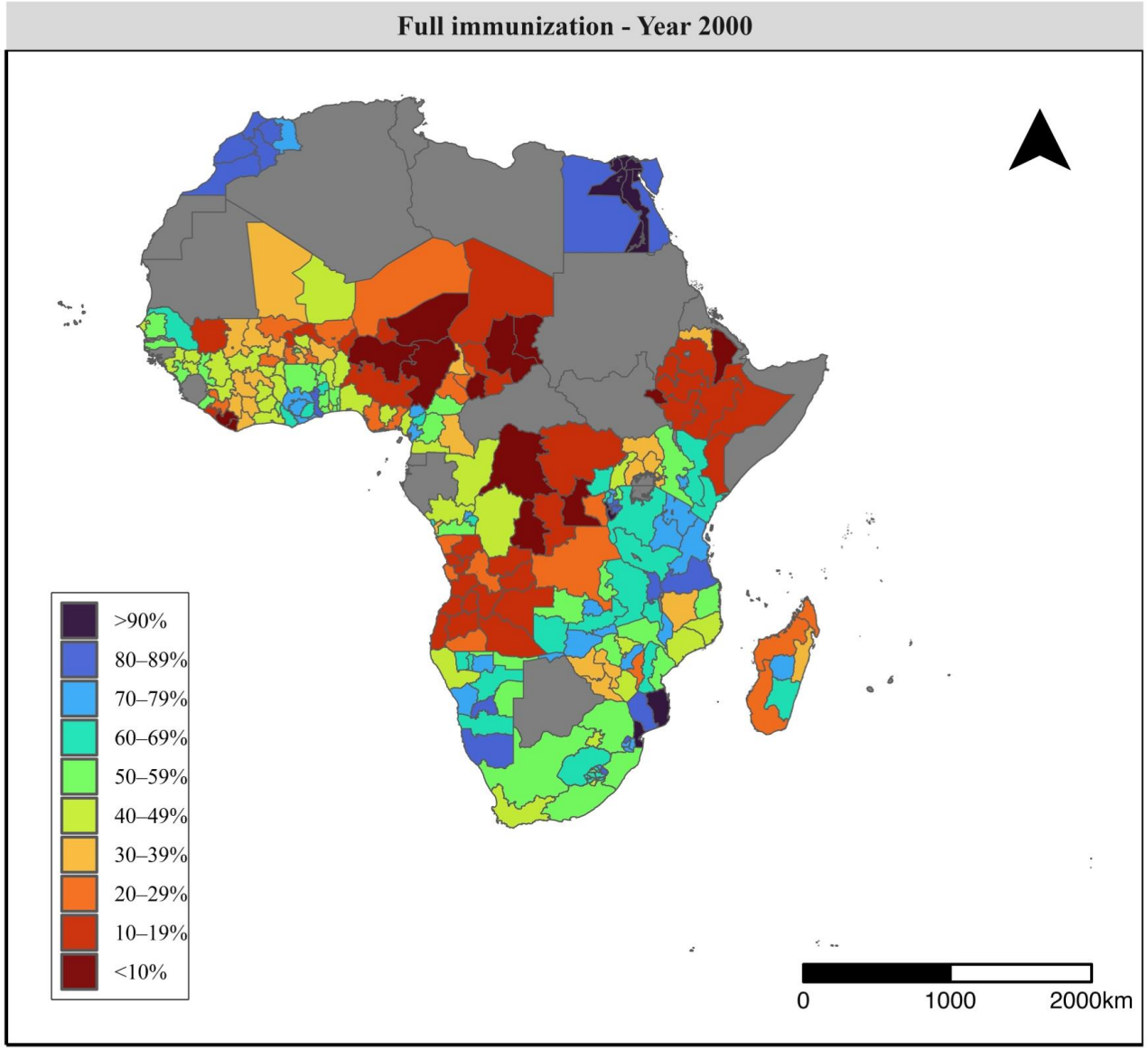
$$AARC = 100 * \left[\left(\frac{P_n}{P_0}\right)^{\frac{1}{N}} - 1\right]$$

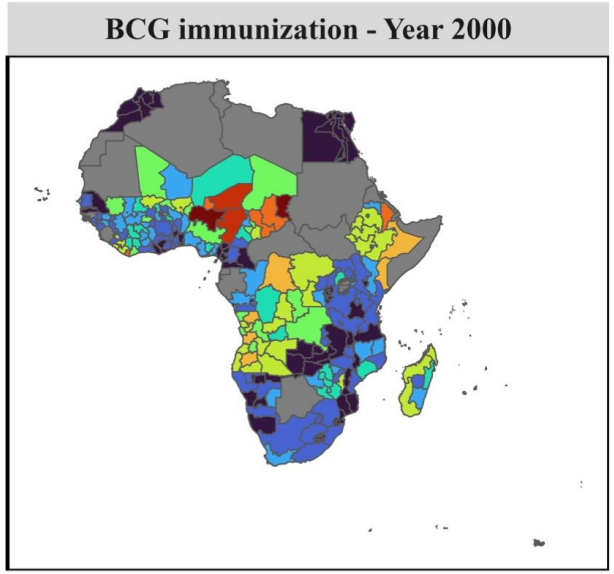
where: P_n = coverage in the later time period; P_0 = coverage in the earlier time period; N = number of years in the interval.

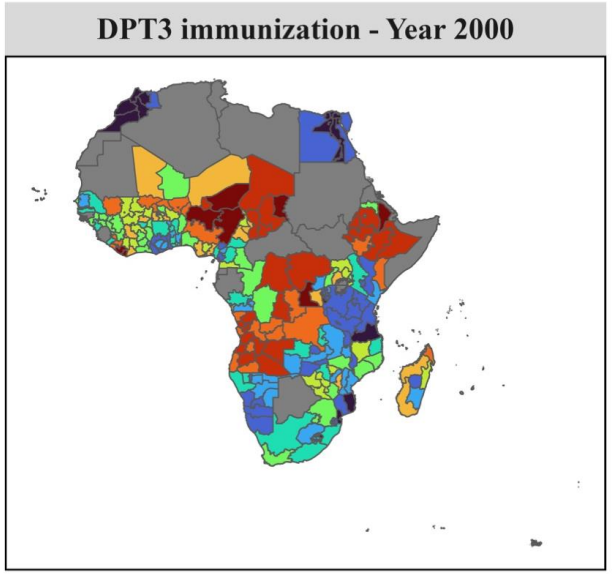
3. RESULTS

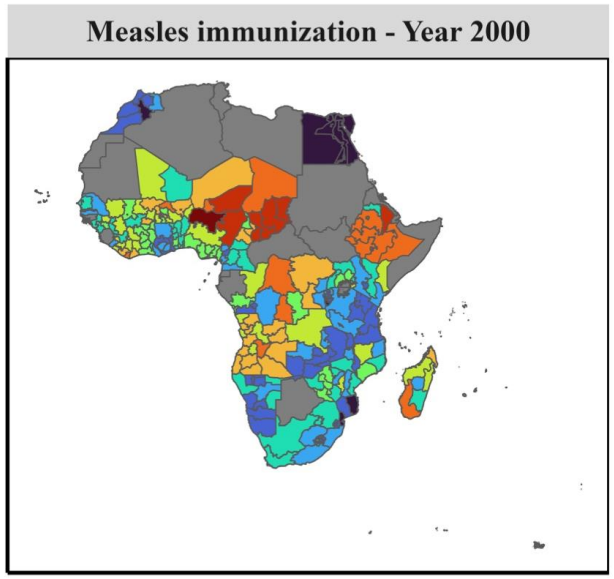

SDI
Full immunization
BCG immunization
Measles immunization
Polio3 immunization
DPT3 immunization
AARC
Reach
Year 2000
Year 2020
Year 2030
South Africa 1.7 1/7
Egypt -0.8* 1/4
Namibia 0.7* 8/13
Eswatini 0.6 4/4
Congo Brazzaville -2.4* 0/4
Ghana 0.8* 6/8
Morocco 0.4 6/6
Nigeria 4.6* 2/6
Kenya 1.9* 8/8
Lesotho 0.5 3/10
Zambia 0.8* 6/8
Cameroon 0.5* 3/11
Zimbabwe 2.7* 9/10
Angola 1.5 0/18
Rwanda 1.2* 5/5
Tanzania 0.6* 4/6
Togo 1.8 3/5
Cote d'Ivoire 2.1 2/11
Uganda 2.8* 4/4
Madagascar 2.1* 5/6
Senegal 1.9* 3/4
Malawi 1.0* 3/3
Congo DR 4.4* 5/11
Liberia 4.3* 5/5
Benin 0.9* 2/6
Ethiopia 5.5* 5/11
Guinea -2.3* 0/8
Mozambique 0.8* 4/11
Burundi -0.1 2/4
Mali 2.6* 3/8
Burkina Faso 4.2* 13/13
Chad 6.6* 0/6
Niger 6.4* 5/6
0.6 7/7
0.0 4/4
0.2* 12/13
0.2 4/4
0.5* 4/4
0.4* 8/8
0.0 6/6
2.5* 3/6
0.6* 8/8
0.1* 10/10
0.2* 8/8
0.1 8/11
1.3* 10/10
0.8 7/18
0.1* 5/5
0.4* 6/6
0.4 5/5
0.8 7/11
0.8* 4/4
1.4* 5/6
0.3* 3/4
0.3* 3/3
1.8* 10/11
2.8* 5/5
-0.1 4/6
1.8* 7/11
-0.6* 2/8
0.4* 11/11
-0.1 4/4
0.9* 7/8
1.3* 13/13
3.1* 3/6
3.2* 6/6
0.8 6/7
-1.9* 1/4
0.6* 12/13
0.4 4/4
1.5* 2/4
0.5* 7/8
0.3 6/6
2.6* 2/6
1.1* 8/8
0.5* 8/10
0.3* 8/8
0.0 3/11
1.6* 9/10
0.3 2/18
0.6* 5/5
0.6* 6/6
1.6 3/5
1.8 2/11
1.6* 4/4
2.0* 5/6
1.0* 3/4
0.6* 3/3
1.8* 8/11
2.1* 5/5
0.5* 1/6
3.4* 7/11
-1.8* 0/8
0.6* 5/11
0.1 4/4
1.5* 4/8
3.2* 13/13
6.3* 4/6
4.3* 6/6
1.0 3/7
0.1* 4/4
0.1 9/13
0.4 4/4
-1.4* 0/4
0.6* 8/8
0.2 6/6
2.8* 4/6
1.1* 8/8
0.2 5/10
0.6* 7/8
-0.1 6/11
1.8* 9/10
0.2 0/18
0.5* 5/5
0.2* 6/6
0.9 5/5
1.1 6/11
1.7* 4/4
1.5* 4/6
1.0* 4/4
0.5* 3/3
3.6* 11/11
3.9* 5/5
0.0 3/6
2.5* 6/11
-0.6* 0/8
0.9* 10/11
0.2* 4/4
1.5* 5/8
2.6* 13/13
2.6* 1/6
3.3* 6/6
1.8 2/7
0.2* 4/4
0.3* 7/13
0.3 4/4
-2.4* 0/4
0.7* 7/8
0.2 6/6
4.5* 4/6
1.3* 8/8
0.3 7/10
0.7* 8/8
0.6* 5/11
2.2* 10/10
1.7 0/18
0.7* 5/5
0.2* 6/6
1.3 3/5
2.1 3/11
2.6* 4/4
1.9* 5/6
1.2* 4/4
0.6* 3/3
3.9* 8/11
4.3* 5/5
0.5* 3/6
4.5* 7/11
-1.0* 0/8
0.7* 6/11
0.3* 4/4
2.5* 7/8
3.3* 13/13
4.3* 0/6
6.0* 6/6
0 20 40 60 80 100
Immunization coverage (%)

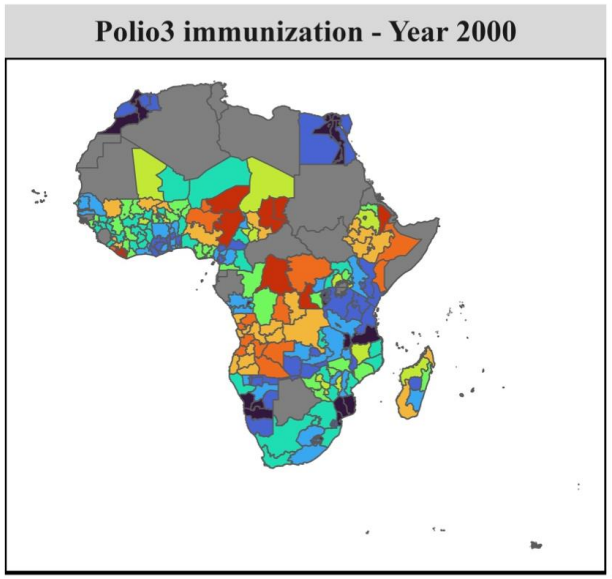
Map of child immunization coverage at regional levels in Year 2000



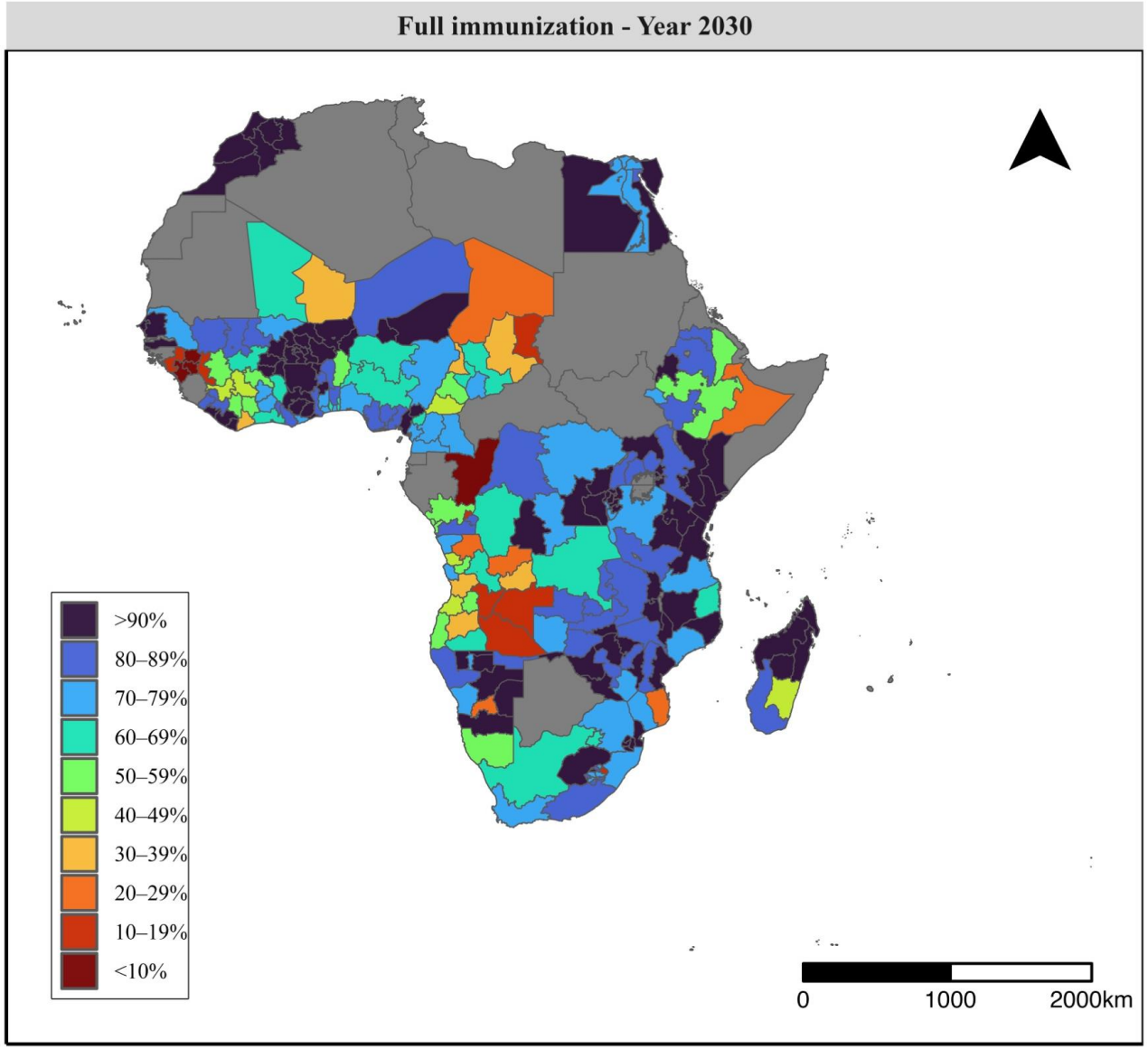


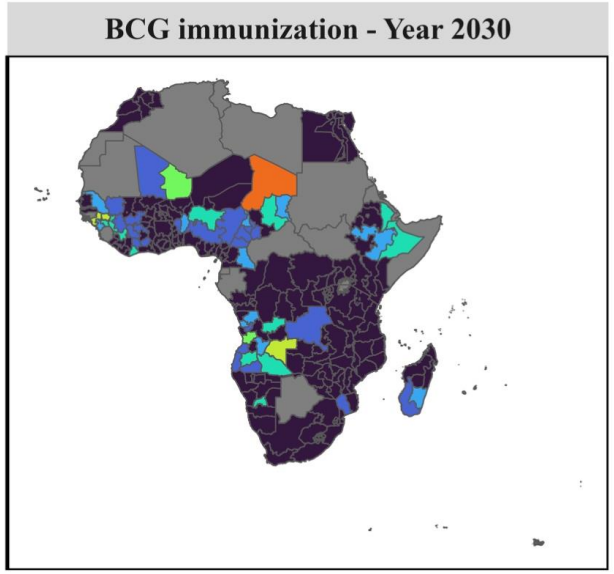


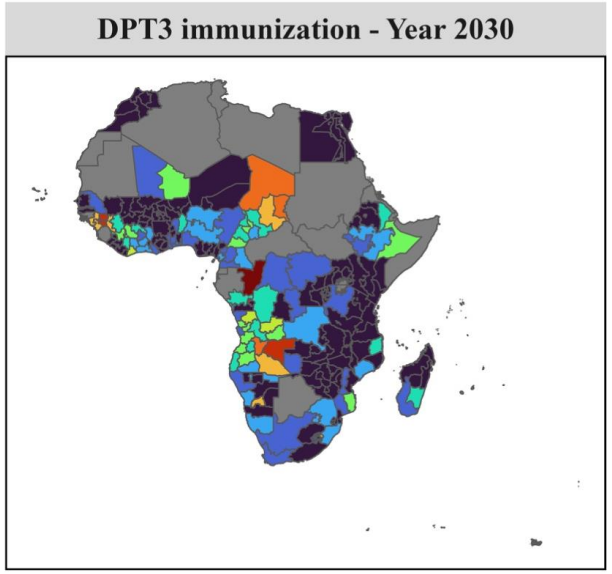


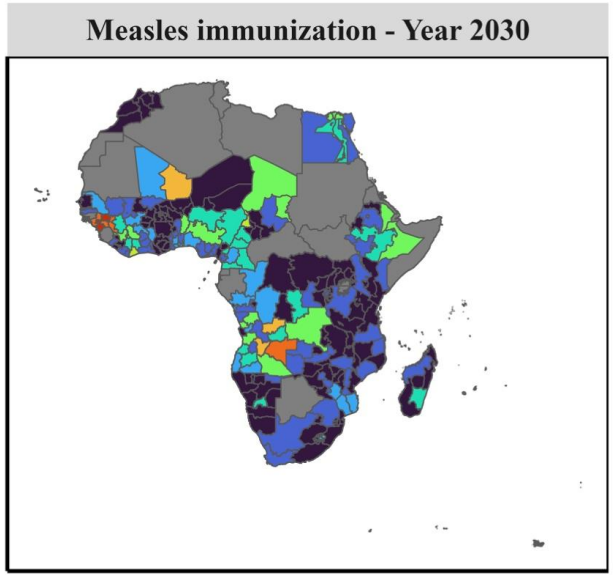


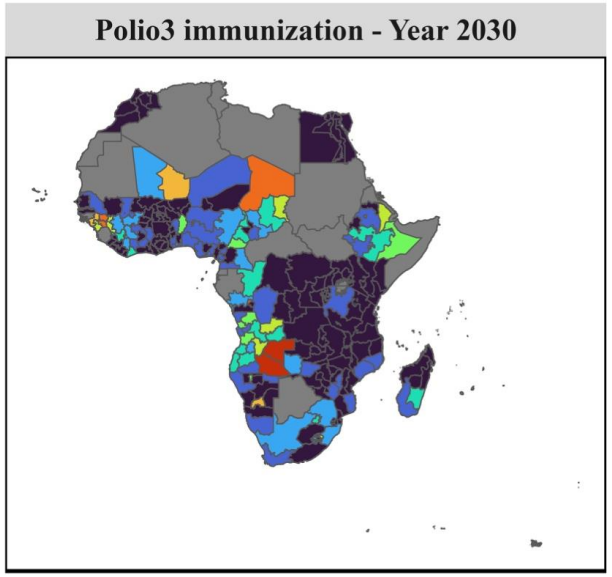
Map of child immunization coverage at regional levels in Year 2030

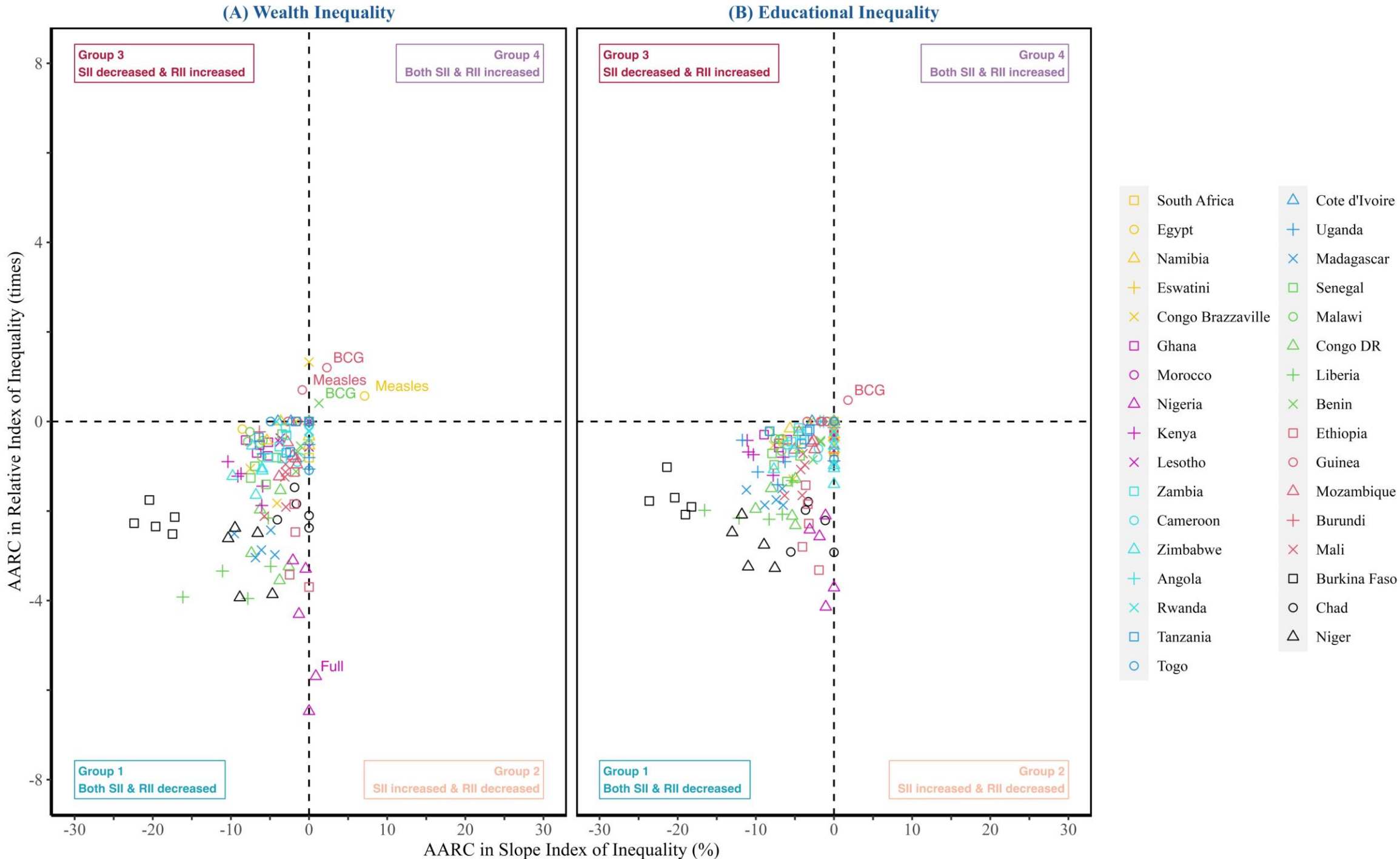











(A) Wealth Inequality
(B) Educational Inequality
Group 3
SII decreased & RII increased
Group 4
Both SII & RII increased
Group 1
Both SII & RII decreased
Group 2
SII increased & RII decreased
BCG
Measles
BCG
Measles
Full
BCG
AARC in Relative Index of Inequality (times)
AARC in Slope Index of Inequality (%)
8
4
0
-4
-8
-30
-20
-10
0
10
20
30
South Africa
Egypt
Namibia
Eswatini
Congo Brazzaville
Ghana
Morocco
Nigeria
Kenya
Lesotho
Zambia
Cameroon
Zimbabwe
Angola
Rwanda
Tanzania
Togo
Cote d'Ivoire
Uganda
Madagascar
Senegal
Malawi
Congo DR
Liberia
Benin
Ethiopia
Guinea
Mozambique
Burundi
Mali
Burkina Faso
Chad
Niger

4. CONCLUSIONS

Conclusions

- We observed **slow progress** in full immunization in most African countries, including those with the highest SDI levels, such as South Africa, Egypt, Congo Brazzaville, and Nigeria.

⇒ **Economic factors alone** may not be sufficient to significantly improve vaccination coverage

⇒ **More effective programs** are needed to address these gaps.

- We observed **regional variations**. While we projected improvements in child vaccinations at the regional level, some regions in Central Africa still show low coverages.
- **Socioeconomic-related inequalities persist**, although the gaps are narrowing over time in most countries, with some exceptions.
- Most regions show a decrease in both the SII and RII, indicating **reduced inequality in absolute and relative terms**. However, some regions display increasing inequality, which warrants further consideration.

Thank you!

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