Effect of preventive chemotherapy with praziquantel on schistosomiasis among school-aged children in sub-Saharan Africa: a spatiotemporal modelling study

Christos Kokaliaris, Amadou Garba, Martin Matuska, Rachel N Bronzan, Daniel G Colley, Ameyo M Dorkenoo, Uwem F Ekpo, Fiona M Fleming, Michael D French, Achille Kabore, Jean B Mbonigaba, Nicholas Midzi, Pauline N M Mwinzi, Eliézer K N'Goran, Maria Rebollo Polo, Moussa Sacko, Louis-Albert Tchuem Tchuenté, Edridah M Tukahebwa, Pitchouna A Uvon, Guojing Yang, Lisa Wiesner, Yaobi Zhang, Jürg Utzinger, Penelope Vounatsou

Summary

Background Over the past 20 years, schistosomiasis control has been scaled up. Preventive chemotherapy with praziquantel is the main intervention. We aimed to assess the effect of preventive chemotherapy on schistosomiasis prevalence in sub-Saharan Africa, comparing 2000–10 with 2011–14 and 2015–19.

Methods In this spatiotemporal modelling study, we analysed survey data from school-aged children (aged 5–14 years) in 44 countries across sub-Saharan Africa. The data were extracted from the Global Neglected Tropical Diseases database and augmented by 2018 and 2019 survey data obtained from disease control programmes. Bayesian geostatistical models were fitted to *Schistosoma haematobium* and *Schistosoma mansoni* survey data. The models included data on climatic predictors obtained from satellites and other open-source environmental databases and socioeconomic predictors obtained from various household surveys. Temporal changes in *Schistosoma* species prevalence were estimated by a categorical variable with values corresponding to the three time periods (2000–10, 2011–14, and 2015–19) during which preventive chemotherapy interventions were scaled up.

Findings We identified 781 references with relevant geolocated schistosomiasis survey data for 2000–19. There were 19166 unique survey locations for *S haematobium* and 23861 for *S mansoni*, of which 77% (14757 locations for *S haematobium* and 18372 locations for *S mansoni*) corresponded to 2011–19. Schistosomiasis prevalence among school-aged children in sub-Saharan Africa decreased from 23·0% (95% Bayesian credible interval 22·1–24·1) in 2000–10 to 9·6% (9·1–10·2) in 2015–19, an overall reduction of 58·3%. The reduction of *S haematobium* was 67·9% (64·6–71·1) and that of *S mansoni* 53·6% (45·2–58·3) when comparing 2000–10 with 2015–19.

Interpretation Our model-based estimates suggest that schistosomiasis prevalence in sub-Saharan Africa has decreased considerably, most likely explained by the scale-up of preventive chemotherapy. There is a need to consolidate gains in the control of schistosomiasis by means of preventive chemotherapy, coupled with other interventions to interrupt disease transmission.

Funding European Research Council and WHO.

Introduction

Schistosomiasis is a water-based disease caused by parasitic trematode worms of the genus *Schistosoma*.[1] In 2017, the global burden of schistosomiasis was estimated at 1·4 million disability-adjusted life-years.[2] WHO reported that 229 million people were affected by schistosomiasis in 2015, with more than 90% of them living in sub-Saharan Africa, 54% of whom were school-aged (aged 5–14 years) children.[3] The two main *Schistosoma* species affecting people in Africa are *Schistosoma haematobium* (causing urogenital schistosomiasis) and *Schistosoma mansoni* (causing intestinal schistosomiasis). In 2001, the World Health Assembly endorsed a resolution that emphasised morbidity control through preventive chemotherapy with

praziquantel as the global strategy and set a target of regularly treating at least 75% of school-aged children by the year 2010. Revitalising schistosomiasis control efforts in 2012, WHO put forward the 2020 targets (a series of action points, main targets, and milestones for accelerating work to overcome the global effect of neglected tropical diseases, including schistosomiasis, the ultimate goal being disease eradication) and established a roadmap to get there.[4] Endemic countries were urged to scale-up schistosomiasis control interventions and strengthen surveillance, improve the environment to decrease disease transmission, and ensure access to praziquantel.[4]

Before the early 2000s, preventive chemotherapy using praziquantel was not widespread in sub-Saharan Africa,

Evidence before this study

Schistosomiasis is a neglected tropical disease that is mainly concentrated in sub-Saharan Africa. In 2012, WHO published a roadmap for the control and elimination of the disease and set targets to be reached by 2020. Over the past 20 years, control efforts against schistosomiasis have been scaled up, with preventive chemotherapy using praziquantel being the main intervention. There is a need to evaluate the effect of these increased control efforts on the distribution of schistosomiasis and to estimate progress made towards the WHO targets. In 2015, Lai and colleagues published maps of schistosomiasis prevalence across sub-Saharan Africa during 2000–12 and estimated that 122 million doses of praziquantel were required for 228 million school-aged children in 2012 using survey data from 1980 to 2012.

Added value of this study

We provide updated maps of schistosomiasis prevalence in sub-Saharan Africa at high resolution covering 2000–19, by including the latest available epidemiological data that correspond with periods in which preventive chemotherapy was scaled up. In our analysis, we assess the effect of

preventive chemotherapy using praziquantel on schistosomiasis prevalence in school-aged children, overall and by species. We provide estimates of schistosomiasis prevalence reduction by country during the scaling up of praziquantel by comparing data from 2015–19 with 2000–10. We also update the estimates of schistosomiasis prevalence and treatment needs for each sub-Saharan African country using population data from 2020, to compare them with the 2020 WHO goals. Our modelling accounts for spatial confounding in the covariates, which enables an accurate estimation of the effect of each risk factor.

Implications of all the available evidence

Our research should assist policy makers to plan their future schistosomiasis control strategies according to the prevalence trends from the past 5–10 years; provide a measure of programme assessment and evaluation by using prevalence estimates before, during, and after preventive chemotherapy; and provide evidence on the effect of socioeconomic and environmental factors (eg, improved sanitation and distance from freshwater bodies) to be considered for future supplementary control projects.

which changed in 2005 when 250 million praziquantel doses were pledged to be provided every year by Merck. From 2002 onwards, preventive chemotherapy efforts for schistosomiasis were scaled up in the form of mass drug administration programmes. A WHO report revealed that approximately 76·2 million school-aged children and 19·1 million adults were treated with praziquantel in 2018, corresponding to 61·2% treatment coverage for children and 18·2% treatment coverage for adults.[3] By contrast, in 2006, only 7 million individuals were treated. In 2017, 17 African countries had achieved the 75% treatment coverage target for school-aged children.[3] However, difficulties accessing praziquantel for at-risk adult populations and preschool-aged children remain a key issue in further scaling up control efforts. Over the past 20 years, praziquantel has been targeted at school-aged children and made available through WHO to ministries of health free of charge.[5]

Complementary control interventions include access to clean water and improved sanitation,[6,7] snail control, and behaviour change.[8,9] These approaches have not been applied widely in sub-Saharan Africa because there are insufficient human and financial resources and challenges in identifying water bodies containing infected intermediate-host snails.[5]

In this study, we estimate the effect of preventive chemotherapy on schistosomiasis prevalence across sub-Saharan Africa. We aimed to assess the changes in the geographical distribution of schistosomiasis, comparing 2000–10 (the early stages of scaling up the control programmes) with 2011–14 (intermediate period)

and 2015–19 (after substantial scale-up efforts), and provide updated estimates of treatment needs per country.

Methods

Prevalence data

Cross-sectional survey data pertaining to *S haematobium* and *S mansoni* infection prevalence in the 2000–19 period were extracted from the Global Neglected Tropical Diseases database.[10] Notably, Global Neglected Tropical Diseases compiles survey data through systematic reviews of published research, coupled with grey literature from country programmes and data from the Expanded Special Project for Elimination of Neglected Tropical Diseases (ESPEN).[11]

To supplement data available in the Global Neglected Tropical Diseases database, we did a systematic review following PRISMA guidelines, with strict inclusion and extraction criteria to ensure that high-quality data were included in the analysis.[12] We searched PubMed, ISI Web of Science, and African Journals Online from Jan 1, 2000, to May 29, 2020, without language restrictions, for surveys that reported schistosomiasis prevalence data for countries in sub-Saharan Africa. The search string included the following criteria: "schisto* (OR mansoni, OR bilhar*, OR haema*) AND sub-Saharan Africa (OR Angola, OR Benin, OR Botswana, OR Burkina Faso, OR Burundi, OR Cameroon, OR Central African Republic, OR Chad, OR Congo*, OR Côte d'Ivoire, OR Democratic Republic of the Congo, OR Djibouti, OR Equatorial Guinea, OR Eritrea, OR Eswatini, OR Ethiopia, OR

Kigali, Rwanda
(J B Mbonigaba MPH);
Department of Medical Microbiology, College of Health Sciences, University of Zimbabwe, Harare, Zimbabwe
(Prof N Midzi PhD); **Center for Global Health Research, Kenya Medical Research Institute, Kisumu, Kenya**
(P N M Mwinzi PhD); **Expanded Special Project for Elimination of Neglected Tropical Diseases, WHO, Regional Office for Africa, Brazzaville, Congo**
(P N M Mwinzi, M R Polo PhD); **Unité de Formation et de Recherche Biosciences, Université Félix Houphouët-Boigny, Abidjan, Côte d'Ivoire**
(Prof E K N'Goran PhD); **Centre Suisse de Recherches Scientifiques en Côte d'Ivoire, Abidjan, Côte d'Ivoire**
(Prof E K N'Goran); **Department of Diagnostic and Biomedical Research, Institut National de Recherche en Santé Publique, Bamako, Mali** (M Sacko PhD); **Laboratory of Parasitology and Ecology, Department of Animal Biology and Physiology, Faculty of Science, University of Yaoundé I, Yaoundé, Cameroon**
(Prof L-A Tcheum-Tchuenté PhD); **Centre for Schistosomiasis and Parasitology, Yaoundé, Cameroon**
(Prof L-A Tcheum-Tchuenté); **Vector Control Division, Ministry of Health, Kampala, Uganda** (E M Tukahebwa PhD); **Neglected Tropical Diseases Unit, Ministère de la Santé Publique, Kinshasa, Democratic Republic of the Congo**
(P A Uvon PhD); **Regional Office for Africa, Helen Keller International, Dakar, Senegal**
(Y Zhang PhD)

Correspondence to:
Dr Penelope Vounatsou, Swiss Tropical and Public Health Institute, CH-4002 Basel, Switzerland
penelope.vounatsou@ swisstph.ch

For the **Global Neglected Tropical Diseases database** see
http://www.gntd.org

Gabon, OR Gambia, OR Ghana, OR Guinea, OR Guinea-Bissau, OR Kenya, OR Lesotho, OR Liberia, OR Madagascar, OR Malawi, OR Mali, OR Mauritania, OR Mozambique, OR Namibia, OR Niger, OR Nigeria, OR Rwanda, OR Senegal, OR Sierra Leone, OR Somalia, OR South Africa, OR South Sudan, OR Sudan, OR Tanzania, OR Togo, OR Uganda, OR Zambia, OR Zimbabwe).

We excluded case reports, in-vitro studies, non-human studies, or those that did not report on schistosomiasis. We additionally excluded studies without prevalence data, those done in specific groups of patients (eg, patients in hospital, people living with HIV) or clearly defined population groups (ie, travellers, military perso-nnel, expatriates, nomads, and displaced or migrating populations, pregnant women, neonates) not represen-tative of the general population, studies that used either indirect diagnostic techniques (because such tests distinguish between active and cleared infection) or direct stool smear (because of low diagnostic sensitivity), reports of case-control studies, clinical trials, pharma-cological studies (except control groups without anthel-mintic intervention), intervention studies (except for baseline data or control groups), studies that reported on species other than S haematobium and S mansoni, and surveys done before 2000, that were not community based or school based, or were done in places where population deworming had been done within 1 year, or study findings reported aggregated within regions (ie, administrative division of level one).

The search strategy and selection criteria are described in detail in the appendix (pp 1–2) and in a previous publication.[13] Quality control was applied for each country on approximately 30% of the data, which were selected at random and embedded in the GNTD database as a function written in Javascript Survey. Locations with missing coordinates were geolocated using Google Maps and georeferenced school databases such as the Humanitarian Data Exchange.Relevant survey data were extracted and entered in the Global Neglected Tropical Diseases database.

Data on covariates

Socioeconomic data on improvements in drinking water, sanitation, and infant mortality rates during 2000–19 were obtained from Demographic and Health Surveys, Multiple Indicator Cluster Surveys, and World Health Surveys. Socioeconomic survey data were not available at yearly basis. Therefore, socioeconomic data from these surveys were aggregated in the 2000–10, 2011–14, and 2015–19 time periods as per schistosomiasis prevalence data and were aligned to the appropriate countries.

Environmental proxies (including land surface temperature [LST] during the day [LSTD] and at night [LSTN], normalised difference vegetation index [NDVI], rainfall, bioclimatic variables, agro-ecological zones and distance to freshwater bodies) were downloaded from remote-sensing satellite sources and model-based gridded surfaces (appendix p 3). Population data for 2010–19 were extracted from the WorldPop database. The national preventive chemotherapy coverage for schistosomiasis in sub-Saharan Africa for each country and year was obtained from a publicly available WHO database.[14] A description of the raw data and their sources is provided in the appendix (p 3).

Statistical modelling

We used Bayesian restricted, geostatistical, hierarchical models to predict the prevalence of S haematobium and S mansoni across sub-Saharan Africa (appendix p 5), relating cross-sectional disease survey data with socio-economic and environmental predictors, accounting for spatial confounding in the covariates.[15] The models included a temporal indicator variable for the periods of 2000–10 (baseline), 2011–14, and 2015–19. The socioeconomic predictors were linked with the prevalence data as areal exposures, aggregated at the first-level administrative unit because of misalignment. The environmental predictors LST, NDVI, and rainfall were summarised by yearly averages and linked to the survey data according to the corresponding year. The bioclimatic predictors were obtained as long-term averages between 1970 and 2000 and linked to the survey data according to the geographical location. Potential socioeconomic and environmental predictors resulted in a large number of models. All models were fitted to the environmental and socioeconomic predictors and the models with the best predictive ability (minimum log conditional predictive ordinate score)[16,17] for S haematobium and S mansoni prevalence were used for inference and predictions. Disease heterogeneity can vary between ecological zones.[18] Hence, we validated the assumption of non-stationarity (ie, implying that spatial correlation varies in space) by introducing the agroecological zone covariates (ie, humid, arid, highlands, semiarid, and subhumid) in the covariance structure of the spatial Gaussian process. Furthermore, we examined the hypothesis of disease prevalence distribution depending on the geographical and temporal variation of the data, by implementing spatiotemporal geostatistical models.[19,20] We obtained two separate models, one for each species, differing by the associated covariates and spatial heterogeneity. Parameter estimates were summarised using posterior medians and the corresponding 95% Bayesian credible intervals (BCI) obtained from the 0·025 and 0·975 quantiles of the posterior distribution of the parameter. The effect of a predictor was considered to be statistically important if the 95% BCI did not include a 0. Model validation was done through out-of-sample pre-dictions, leaving out 10% of the data repeated 20 times.

To estimate the effect of preventive chemotherapy on schistosomiasis prevalence for a given country and year, we calculated the mean national coverage of preventive chemotherapy over the past 3 years and used it as a covariate in the models. The number of school-aged
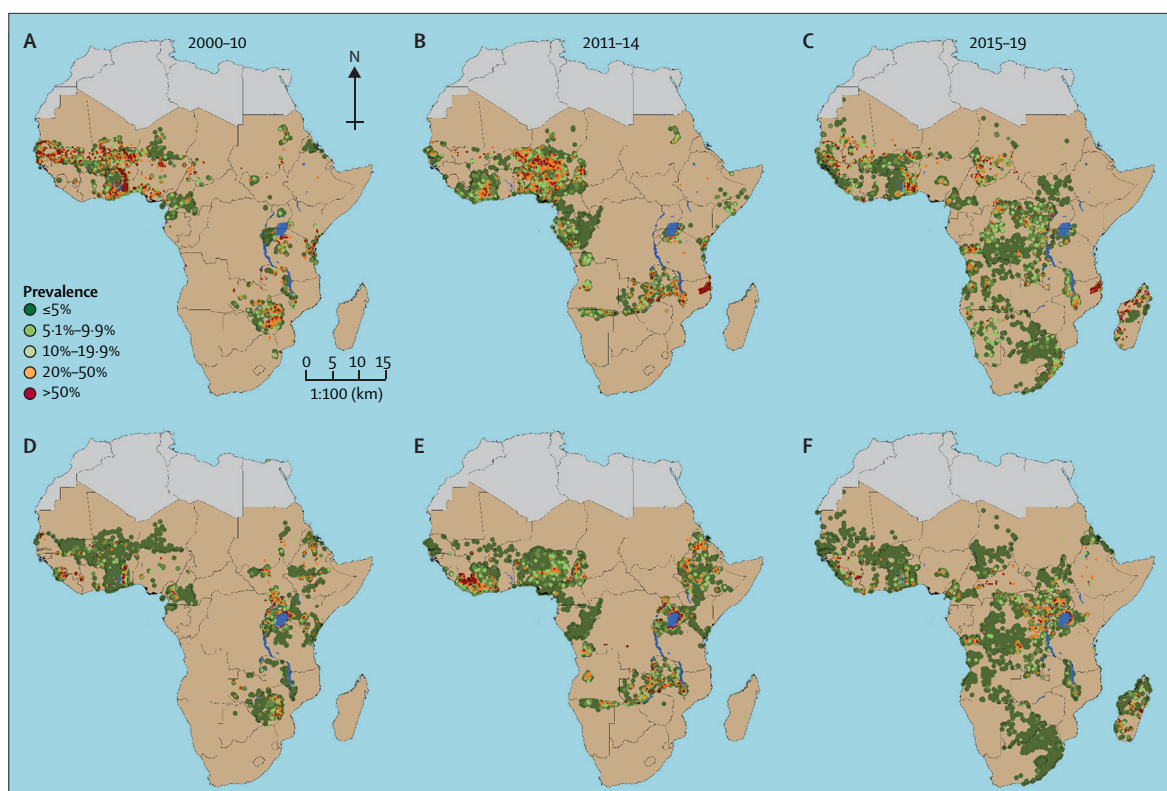
Figure 1: Observed prevalence of *Schistosoma* species in sub-Saharan Africa
(A–C) *Schistosoma haematobium*. (D–F) *Schistosoma mansoni*.

children infected with *Schistosoma* species was estimated by overlaying predicted *Schistosoma* species prevalence surfaces with gridded surfaces of population counts at high spatial resolution (100 m × 100 m). Preventive chemotherapy needs for each country were calculated in accordance with WHO guidelines (appendix p 8).[21] We used R (version 3.3.3) for the statistical analysis. Modelling details are presented in the appendix (pp 5–6, 8).

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the paper.

Results

We identified 781 relevant references from the systematic review and national control programmes, including data provided by WHO after consultation with ministries of health and the ESPEN portal. A flowchart of the total number of articles searched and those deemed relevant after applying our inclusion and exclusion criteria is presented in the appendix (p 2). There were 19 166 unique survey locations for *S haematobium* and 23 861 unique survey locations for *S mansoni*, of which 77% (14 757 locations for *S haematobium* and 18 372 locations for *S mansoni*) corresponded to 2011–19. From the 26 780 unique locations, 15 344 (57·3%) were obtained from peer-reviewed studies,

7739 (28·9%) from control programmes, and 3695 (13·8%) from ESPEN records. The main diagnostic method for *S haematobium* was urine filtration (done in 340 [77%] of 444 surveys). The Kato-Katz method was the predominant approach for *S mansoni* (421 [96%] of 437 surveys). The raw prevalence data by *Schistosoma* species and survey period are presented in figure 1. Most of the surveys were school-based: 174 (97%) of 180 schistosomiasis surveys were school-based during 2000–10, and 594 (99%) of 601 were school-based in 2011–19. A detailed description of the data, stratified by country and survey period, is provided in the appendix (p 4).

Risk factor analysis showed that high praziquantel coverage during a 3-year period and higher proportion of households with access to improved sanitation facilities were related to lower risk of infection for *S haematobium* and *S mansoni* (table 1). Close proximity to freshwater bodies was associated with higher risk of *Schistosoma* species infection. *S haematobium* risk was associated positively with LSTN, NDVI, and the mean diurnal range. Humid agroecological zones, altitude, and the mean temperature of the driest quarter showed negative associations with *S haematobium* risk. *S mansoni* infection risk was associated positively with isothermality, precipitation, and humid agroecological zones (table 1).

Our geostatistical analysis showed that the infection prevalence decreased over time compared with 2000–10

	S haematobium	S mansoni
Stationary geostatistical model		
Risk factors		
Year period		
2000–10	1·00 (ref)	1·00 (ref)
2011–14	–0·98 (–1·05 to –0·91)	–0·09 (–0·18 to 0·01)
2015–19	–1·39 (–1·48 to –1·29)	–1·00 (–1·12 to –0·88)
Mean preventive chemotherapy coverage in the past 3 years (%)	–0·13 (–0·17 to –0·09)	–0·16 (–0·22 to –0·11)
Distance from freshwater bodies		
≥500 m	1·00 (ref)	1·00 (ref)
<500 m	0·42 (0·31 to 0·54)	1·15 (1·03 to 1·27)
Isothermality*	NA	0·30 (0·22 to 0·38)
Precipitation (mm)	NA	0·24 (0·18 to 0·30)
Improved sanitation (%)†	–0·21 (–0·25 to –0·18)	–0·22 (–0·27 to –0·16)
Altitude	–0·64 (–0·72 to –0·57)	NA
Land surface temperature at night (°C)	0·17 (0·10 to 0·23)	NA
Normalised difference vegetation index	0·28 (0·24 to 0·33)	NA
Mean diurnal range (°C)	0·12 (0·07 to 0·17)	NA
Mean temperature of driest quarter (°C)	–0·32 (–0·39 to –0·25)	NA
Precipitation of wettest month	–0·18 (–0·22 to –0·13)	NA
Agroecological zone		
Humid	1·00 (ref)	1·00 (ref)
Arid	0·48 (0·24 to 0·72)	–1·54 (–2·05 to –1·02)
Highlands	1·65 (1·48 to 1·82)	–0·50 (–0·63 to –0·37)
Semiarid	2·16 (2·02 to 2·29)	–0·77 (–0·99 to –0·54)
Subhumid	1·30 (1·19 to 1·40)	–0·31 (–0·45 to –0·17)
Geographical variation parameters		
Range (km)	133·5 (122·1 to 146·2)	222·1 (200·1 to 252·3)
Non-spatial variance (σ_e^2)	1·44 (1·41 to 1·46)	1·42 (1·39 to 1·45)
Spatial variance (σ^2)	2·20 (2·09 to 2·31)	4·40 (4·07 to 4·84)
Non-stationary geostatistical model‡		
Spatial variance (σ^2)§		
Agroecological zone		
Humid	1·00 (ref)	1·00 (ref)
Arid	2·50 (2·20 to 2·87)	2·37 (1·96 to 2·89)
Highlands	2·67 (2·43 to 2·93)	3·20 (2·99 to 3·43)
Semiarid	2·15 (1·98 to 2·32)	3·02 (2·78 to 3·28)
Subhumid	1·38 (1·35 to 1·41)	1·42 (1·38 to 1·46)

Data are posterior medians (95% Bayesian credible intervals) unless otherwise stated. NA=not applicable. *Isothermality is calculated by the ratio of the mean diurnal range (difference between minimum and maximum daily temperature) to the annual temperature range. †Improved sanitation refers to connection to a public sewer or to a septic system, pour-flush latrine, simple pit latrine, or ventilated improved pit latrine. ‡Risk factors, range, and non-stationary variance are similar to the non-stationary geostatistical model and were omitted. §Spatial variance was modelled as a function of the agroecological zone categories.

Table 1: Estimates for covariates obtained from Bayesian geostatistical stationary and non-stationary models for *Schistosoma haematobium* and *Schistosoma mansoni* in sub-Saharan Africa

(table 1). Population-adjusted estimates of the prevalence reduction (ie, relative to prevalence during 2000–10) and the prevalence ratio (table 2) between different time periods confirmed that there was a statistically important (determined by 95% BCI) drop in prevalence for both *Schistosoma* species across sub-Saharan Africa (table 2). For the 44 countries in sub-Saharan Africa included in our analysis, we estimated a 67·9% overall relative prevalence

reduction for *S haematobium* and 53·6% reduction for *S mansoni* in 2015–19 compared with 2000–10 (table 2).

The predictive prevalence maps (figure 2) show a decline in prevalence for *S haematobium* and *S mansoni* from 2000–10 to 2011–14 and from 2011–14 to 2015–19. Prediction uncertainty was high in areas with sparse data for both periods (2000–10 to 2011–14 and 2011–14 to 2015–19; appendix p 4). The population-adjusted prevalence of schistosomiasis in sub-Saharan Africa was estimated at 23·0% (95% BCI 22·1–24·1) during 2000–10, which declined to 9·6% (9·1–10·2) by 2015–19 (table 3). In sub-Saharan Africa, the population-adjusted prevalence in 2010 was estimated at 17·4% (16·5–18·5) for *S haematobium* and 7·1% (6·5–7·6) for *S mansoni* (table 3). Estimates based on population data from 2019 suggest a prevalence of 6·2% (5·7–6·7) for *S haematobium* and 3·7% (3·4–4·0) for *S mansoni* (table 3). The countries with the highest prevalence of infection (ie, >40%) in 2000–10 were the Central African Republic, Chad, Guinea, Liberia, and Mozambique. During the same period, Burundi, Equatorial Guinea, Eswatini, Lesotho, and Rwanda had the lowest prevalence (<5%). During 2015–19, we observe that all countries had lower prevalence than the 2000–10 period; however, Guinea remained the country with the highest prevalence (32·6%%).

Among the 223 million school-aged children in 2010, 51 million (23·0%, 95% BCI 22·1–24·1) were infected with either species (table 3), and approximately 111 million children (109–113) were in need of treatment according to WHO praziquantel guidelines (table 4). In 2019, of 288 million school-aged children, 28 million (9·6%, 9·1–10·2) were infected with either *S haematobium* or *S mansoni* (table 3), and 112 million (110–113) required praziquantel in accordance with WHO guidelines (table 4).

Model validation suggested that our models were able to correctly estimate the prevalence within a 95% BCI in 78% of *S haematobium* locations and 86% of *S mansoni* locations on average. The mean absolute error was 8% for *S haematobium* and 5% for *S mansoni*, with a low percentage of prevalence underestimation of around 2% (appendix p 7).

Discussion

We assessed the effect of large-scale preventive chemotherapy on reducing the prevalence of *S haematobium* and *S mansoni* by comparing 2000–10 data (before most countries in sub-Saharan Africa had scaled up their schistosomiasis control programmes) with 2011–14 and 2015–19 data. Additionally, we provide updated estimates of the disease prevalence at high spatial resolution, the number of infected school-aged children, and treatment needs in sub-Saharan Africa for schistosomiasis. Our results should enable disease control programme managers to deliver spatially targeted treatment, according to WHO guidelines, and prioritise disease control in a cost-effective manner. Furthermore, the maps identify regions with high heterogeneity in the geographical

	Relative prevalence reduction (2011–14)			Relative prevalence reduction (2015–19)		
	Schistosomiasis	S haematobium	S mansoni	Schistosomiasis	S haematobium	S mansoni
Angola	39·2%	43·2%	21·9%	58·2%	61·7%	53·6%
Benin	42·8%	44·9%	29·8%	65·4%	65·6%	69·7%
Botswana	41·5%	47·8%	16·5%	59·1%	63·7%	44·6%
Burkina Faso	67·2%	69·5%	50·1%	77·9%	78·5%	70·7%
Burundi	43·7%	67·4%	34·0%	69·7%	80·1%	64·0%
Cameroon	41·1%	53·3%	19·9%	68·1%	73·1%	60·8%
Central African Republic	24·6%	43·6%	14·0%	36·4%	56·7%	23·7%
Chad	34·2%	37·6%	14·8%	50·9%	52·6%	47·1%
Congo	27·3%	46·5%	6·9%	57·4%	67·8%	48·8%
Côte d'Ivoire	36·4%	54·6%	17·8%	54·9%	67·0%	44·4%
Democratic Republic of the Congo	50·1%	53·0%	24·2%	71·6%	73·3%	59·2%
Djibouti	54·0%	60·5%	37·2%	66·0%	68·5%	45·6%
Equatorial Guinea	44·6%	67·2%	21·8%	60·7%	74·5%	48·3%
Eritrea	19·9%	54·8%	2·7%	68·1%	78·4%	61·1%
Eswatini	44·1%	63·5%	24·5%	66·5%	78·3%	54·7%
Ethiopia	32·7%	53·0%	9·9%	59·7%	69·4%	49·3%
Gabon	34·1%	54·2%	8·7%	55·3%	69·0%	35·4%
Gambia	51·0%	52·5%	9·5%	71·6%	72·0%	65·4%
Ghana	46·7%	54·0%	21·9%	64·6%	68·0%	57·5%
Guinea	15·2%	43·8%	7·0%	29·0%	58·6%	20·4%
Guinea-Bissau	45·0%	55·3%	33·0%	64·3%	71·6%	52·9%
Kenya	39·2%	51·0%	18·2%	61·7%	67·4%	55·3%
Lesotho	49·2%	61·0%	8·5%	67·9%	69·7%	61·1%
Liberia	30·1%	51·6%	19·3%	43·1%	58·2%	38·8%
Madagascar*	..	..	..	..	..	..
Malawi	45·7%	51·2%	28·7%	69·4%	70·9%	69·8%
Mali	42·9%	46·6%	35·4%	56·3%	59·3%	55·6%
Mauritania	41·6%	44·4%	25·0%	56·9%	58·7%	48·9%
Mozambique	31·8%	40·4%	17·3%	47·5%	53·0%	43·6%
Namibia	38·8%	49·4%	8·8%	59·4%	64·4%	43·7%
Niger	57·5%	58·7%	42·7%	70·5%	71·3%	63·9%
Nigeria	44·9%	48·6%	21·1%	67·1%	68·7%	59·9%
Rwanda	28·2%	60·3%	20·5%	61·9%	78·6%	57·8%
Senegal	47·5%	52·8%	30·9%	64·5%	67·7%	55·1%
Sierra Leone	44·2%	69·2%	37·8%	51·3%	79·4%	42·5%
Somalia	39·6%	45·3%	14·1%	55·9%	59·8%	49·1%
South Africa	37·3%	46·8%	6·8%	55·5%	60·3%	40·7%
South Sudan	22·3%	48·8%	−1·6%	46·3%	64·3%	32·4%
Sudan	27·9%	45·1%	10·3%	48·7%	62·2%	38·2%
Tanzania	31·9%	46·2%	6·7%	51·6%	59·8%	37·8%
Togo	68·4%	69·7%	65·0%	73·6%	74·7%	69·9%
Uganda	24·9%	53·3%	8·9%	62·0%	71·5%	55·9%
Zambia	31·8%	45·9%	15·5%	56·3%	63·8%	53·9%
Zimbabwe	47·0%	57·9%	22·8%	72·0%	75·8%	65·1%
Total (95% Bayesian credible interval)	39·4% (34·3–43·6)	51·2% (46·9–56·4)	19·5% (9·2–27·3)	60·5% (55·7–64·6)	67·9% (64·6–71·1)	53·6% (45·2–58·3)

Relative prevalence reduction was calculated as the prevalence in 2000–10 minus the prevalence in 2011–14 or 2015–19 divided by the prevalence in 2000–10. For example, the 39·2% relative prevalence reduction of schistosomiasis in Angola during the 2011–14 period suggests that in Angola the schistosomiasis prevalence during 2011–14 decreased by 39·2% compared with the baseline prevalence during 2000–10. *Madagascar only had data available for 2015–19, therefore reduction prevalences could not be calculated.

Table 2: Estimated relative prevalence reduction (percentage decrease of schistosomiasis prevalence) by species and country, comparing 2011–14 and 2015–19 with 2000–10 across sub-Saharan Africa
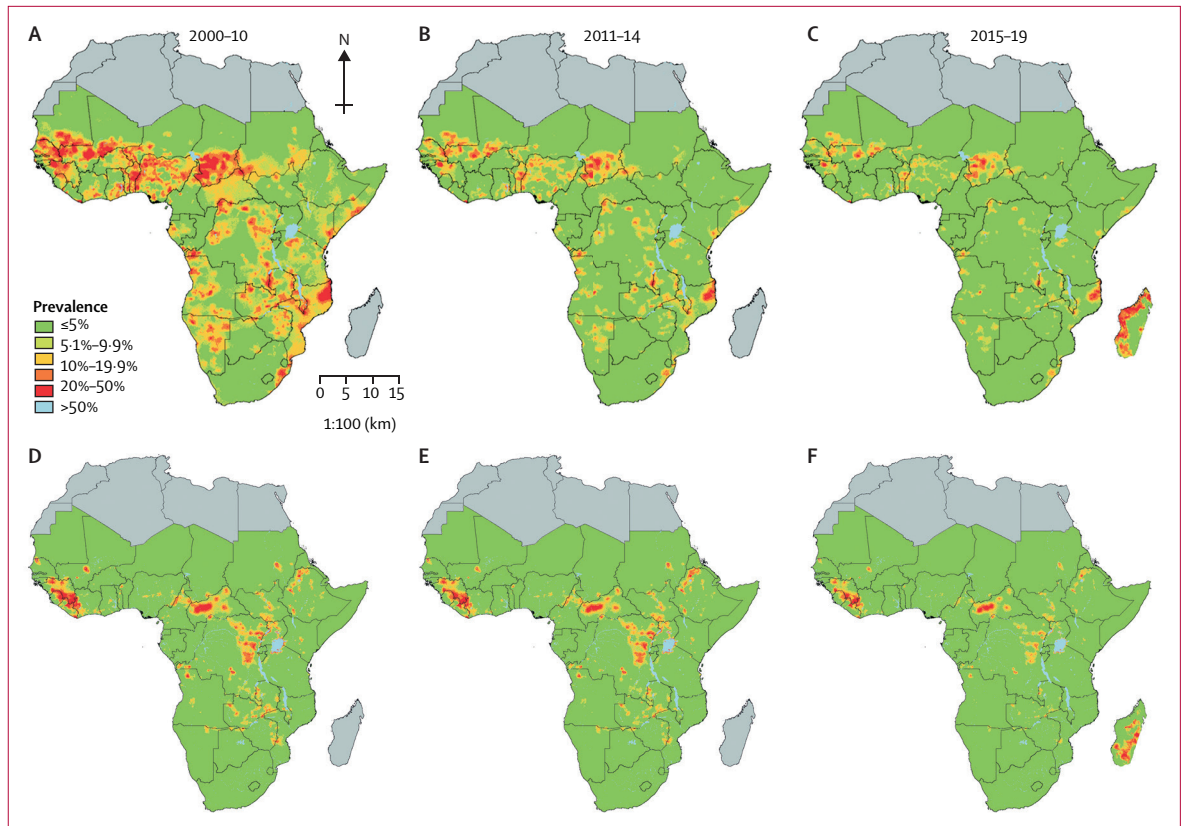
Figure 2: **Schistosomiasis prevalence estimates across sub-Saharan Africa**
Data are posterior predictive median. (A–C) *Schistosoma haematobium.* (D–F) *Schistosoma mansoni.*

distribution of the disease, data sparsity, or large uncertainty in the prevalence estimates and, therefore, could assist control programmes in the design of follow-up surveys for disease monitoring and evaluation.

We estimated that, by comparison with 2000–10, the prevalence of *S haematobium* was reduced by 67·9% and *S mansoni* by 53·6% in 2015–19. However, reductions were not uniform, with variations by country and species. Differences in relative reduction rates between species could be due to the higher effectiveness of single-dose praziquantel against *S haematobium* than *S mansoni.*[22,23]

Countries that had multiple rounds of preventive chemotherapy showed a considerable decline in schistosomiasis prevalence. Our analysis suggests that maintaining high preventive chemotherapy coverage over a 3-year period is associated with reductions in *Schistosoma* species prevalence. Burkina Faso, Burundi, Gambia, Malawi, Niger, and Togo reported national treatment coverage rates above 75% during 2015–19; therefore, further reduction can be expected in these countries in the coming years. Similarly, Cameroon, Congo, and Zimbabwe with reported national preventive chemotherapy coverage of more than 50% during 2015–19 (prevalence >10% in 2000–10) are expected to result in further reductions of schistosoma prevalence. In 2010, the highest estimates of schistosomiasis

population-adjusted prevalence (>40%) were observed in the Central African Republic, Chad, Guinea, Liberia, and Mozambique, with prevalence reduction rates of less than 50% when comparing 2000–10 with 2015–19. In 2019, these same countries had the highest prevalence in sub-Saharan Africa, with all of them reporting low national treatment coverage that were far from the WHO roadmap target of 75%, apart from Liberia, where it was only reached in 2019. Notably, the countries where prevalence was highest did not necessarily correspond to those countries where the number of treatment needs was highest, as treatment needs depend on the population at risk (ie, all population living in an area). Treatment needs in 2019 for the Democratic Republic of the Congo, Ethiopia, Nigeria, and Tanzania amounted to 52 million, with Nigeria requiring approximately 18% (20 million) of the total treatment needs for sub-Saharan Africa.

Preventive chemotherapy campaigns mostly focus on school-aged children, as this age group is considered to be at highest risk of infection and associated morbidity, and schools are a suitable setting for treatment campaigns. Our estimates are based on school-based survey data; there were very few community-based surveys in the Global Neglected Tropical Diseases and other databases. To avoid bias, we did not consider community-based surveys in our

	2010				2014				2019			
	Population (in 1000s)	Schistosomiasis (%)	S haematobium (%)	S mansoni (%)	Population (in 1000s)	Schistosomiasis (%)	S haematobium (%)	S mansoni (%)	Population (in 1000s)	Schistosomiasis (%)	S haematobium (%)	S mansoni (%)
Angola	5321	32.2% (21.4–41.3)	26.6% (16.4–36.4)	6.0% (4.0–16.9)	6488	19.6% (12.8–31.9)	14.9% (8.7–26.8)	4.8% (3.0–10.5)	7721	12.9% (7.5–23.1)	9.7% (5.2–18.6)	2.8% (1.8–8.8)
Benin	2366	36.7% (33.1–41.8)	34.3% (30.8–39.2)	3.4% (2.6–5.1)	2689	21.0% (18.6–24.7)	19.1% (16.5–22.8)	2.4% (1.8–3.3)	3037	12.6% (10.9–15.7)	11.7% (10.0–14.7)	1.0% (0.7–1.5)
Botswana	407	12.5% (7.7–19.8)	10.6% (5.9–17.4)	2.1% (1.0–4.3)	435	7.2% (4.6–12.8)	5.5% (2.8–10.4)	1.8% (0.9–3.5)	474	5.0% (2.6–9.8)	3.7% (1.7–8.4)	1.2% (0.6–2.9)
Burkina Faso	4444	17.5% (14.2–21.3)	15.7% (12.6–19.7)	1.9% (1.2–3.2)	5178	5.7% (4.5–7.7)	4.8% (3.7–6.6)	1.0% (0.6–1.8)	5900	4.0% (3.0–5.5)	3.4% (2.6–4.7)	0.5% (0.3–1.2)
Burundi	2256	4.8% (3.3–7.8)	1.7% (0.6–4.8)	3.1% (2.3–4.4)	2669	2.7% (1.9–4.3)	0.5% (0.2–1.8)	2.0% (1.5–3.0)	3211	1.5% (1.0–2.2)	0.3% (0.1–1.2)	1.1% (0.8–1.6)
Cameroon	5191	15.5% (13.6–17.8)	10.6% (9.3–12.6)	5.4% (4.4–6.9)	5977	9.1% (7.8–10.7)	4.9% (4.2–6.2)	4.2% (3.5–5.5)	6746	5.0% (4.3–6.1)	2.9% (2.3–3.5)	2.1% (1.6–2.9)
Central African Republic	1204	44.6% (34.1–57)	25.7% (17.1–38.8)	24.3% (17.1–35.2)	1304	33.4% (24.9–45.7)	14.4% (8.0–25.2)	21.0% (14.9–32.4)	1369	28.2% (19.9–40.7)	11.2% (5.3–22.4)	18.5% (12.7–29.1)
Chad	3361	40.9% (37.0–45.3)	37.9% (34.0–42.4)	4.9% (3.6–7.1)	3949	27.1% (24.3–31.1)	23.8% (20.9–27.3)	4.3% (3.0–6.2)	4514	20.1% (17.8–22.5)	18.0% (15.7–20.4)	2.6% (1.8–3.9)
Congo	1008	7.8% (6.1–10.5)	6.9% (5.3–9.9)	0.8% (0.5–1.4)	1186	3.8% (2.9–5.6)	3.2% (2.3–4.8)	0.6% (0.3–1.4)	1362	2.2% (1.6–3.2)	1.8% (1.3–2.9)	0.3% (0.2–0.7)
Côte d'Ivoire	5228	21.5% (20–23.4)	12.5% (11.0–14.1)	10.3% (9.2–11.8)	5747	13.7% (12.6–14.9)	5.7% (4.9–6.5)	8.5% (7.6–9.4)	6341	9.6% (8.7–10.8)	4.1% (3.4–5)	5.7% (5–6.7)
Democratic Republic of the Congo	18004	24.6% (22.4–26.8)	15.3% (13.5–17.4)	11.2% (9.7–13.2)	21646	17.9% (16.1–19.7)	8.2% (7.3–9.5)	10.4% (9.1–12.2)	25684	10.3% (9.3–11.8)	4.9% (4.3–5.8)	5.7% (4.7–6.7)
Djibouti	165	13.9% (1.3–56.7)	10.8% (1.0–54.5)	0.9% (0.0–20.8)	163	6.0% (0.5–43.1)	4.0% (0.2–35.9)	0.6% (0.0–19.4)	169	4.0% (0.4–32.7)	3.0% (0.2–30.1)	0.4% (0–9.9)
Equatorial Guinea	281	3.7% (1.9–8.3)	2.0% (1.0–4.5)	1.6% (0.5–4.9)	344	2.0% (1.0–4.3)	0.7% (0.3–1.6)	1.3% (0.5–3.2)	414	1.5% (0.6–3.3)	0.5% (0.2–1.4)	0.8% (0.3–2.7)
Eritrea	1184	6.9% (4.7–9.7)	2.4% (0.9–5.6)	4.4% (3.3–6.2)	1486	5.4% (3.9–7.8)	1.0% (0.3–3.4)	4.4% (3.2–5.6)	1572	2.2% (1.4–3.9)	0.5% (0.1–1.8)	1.6% (1.2–2.7)
Eswatini	269	4.2% (3.0–5.9)	2.2% (1.3–3.4)	1.9% (1.2–3.1)	279	2.3% (1.6–3.3)	0.8% (0.5–1.3)	1.5% (0.9–2.5)	283	1.3% (1.0–2.1)	0.5% (0.3–0.8)	0.9% (0.6–1.6)
Ethiopia	22766	16.4% (11.9–24.1)	10.3% (5.4–17.4)	6.8% (5.7–8.7)	24497	11.0% (7.9–16.3)	5.1% (2.2–9.9)	6.3% (5.0–7.8)	26358	6.5% (4.8–10.7)	3.1% (1.6–7.3)	3.4% (2.5–4.7)
Gabon	372	18.5% (12.1–33.7)	12.6% (8.3–17.3)	6.4% (1.7–25.7)	422	11.4% (6.6–34.6)	5.9% (3.4–9.2)	5.7% (1.5–30.2)	506	8.0% (4.1–27.3)	3.7% (2.3–6.3)	4.2% (0.9–24.6)
Gambia	457	10.0% (8.0–12.5)	9.7% (7.7–12.3)	0.3% (0.1–0.9)	523	4.9% (3.7–6.5)	4.6% (3.5–6.0)	0.2% (0.1–0.6)	606	2.8% (2.1–3.7)	2.7% (2.0–3.6)	0.1% (0.0–0.3)
Ghana	6035	24.1% (20.4–27.8)	19.7% (16.6–23.2)	5.3% (3.2–7.9)	6562	12.7% (10.6–16.4)	9.1% (7.3–11.2)	4.0% (2.6–6.8)	7234	8.5% (6.9–10.9)	6.2% (4.9–8.0)	2.2% (1.4–4.1)
Guinea	3053	45.8% (38.8–51.6)	22.8% (15.8–29.4)	31.8% (25.7–39.6)	3366	38.5% (32.2–47.6)	12.7% (8.5–18.4)	29.6% (23.0–37.8)	3697	32.6% (27.7–38.5)	9.5% (5.8–14.3)	25.2% (19.9–31.2)
Guinea-Bissau	420	15.0% (8.5–38.0)	8.9% (6.4–13.6)	6.4% (0.8–30.0)	478	9.0% (4.0–26.6)	4.0% (2.8–6.3)	4.7% (0.5–23.0)	544	5.3% (2.6–18.4)	2.6% (1.6–4.0)	2.8% (0.4–16.7)
Kenya	10978	15.7% (11.3–27.0)	10.7% (6.4–22.3)	5.6% (4.4–7.0)	12327	9.7% (7.2–15.0)	5.3% (3.0–11.6)	4.5% (3.7–5.7)	13192	5.9% (4.0–11.6)	3.4% (1.7–9.4)	2.5% (2.0–3.9)
Lesotho	422	4.4% (0.8–21.1)	3.1% (0.4–20.3)	0.6% (0.1–6.5)	420	2.2% (0.4–11.7)	1.3% (0.1–10.2)	0.4% (0.1–3.5)	414	1.3% (0.3–9.5)	0.9% (0.1–9.5)	0.2% (0.0–0.8)

(Table 3 continues on next page)

	2010				2014				2019			
(Continued from previous page)	Population (in 1000s)	Schistosomiasis (%)	S haematobium (%)	S mansoni (%)	Population (in 1000s)	Schistosomiasis (%)	S haematobium (%)	S mansoni (%)	Population (in 1000s)	Schistosomiasis (%)	S haematobium (%)	S mansoni (%)
Liberia	982	42·1% (36·4–48·5)	21·7% (15·7–29·6)	26·1% (21·8–32·4)	1130	29·6% (25·4–34·5)	10·9% (6·9–16·3)	20·9% (17·6–25·7)	1237	24·0% (19·6–29·6)	9·0% (5·6–14·7)	16·0% (13·5–19·6)
Madagascar	5674	..	..	..	6258	..	..	..	6838	29·4% (20·0–41·7)	12·2% (8·5–16·5)	18·5% (11·1–29·6)
Malawi	4200	36·0% (33·6–38·4)	31·0% (28·7–33·3)	7·3% (6·1–8·9)	4882	19·5% (18·1–21·3)	15·1% (13·7–16·8)	5·1% (4·4–6·3)	5421	11·0% (10·0–12·0)	9·0% (8·1–10·1)	2·2% (1·8–2·8)
Mali	3918	39·8% (36·5–42·9)	36·1% (32·8–39·5)	6·7% (5·2–8·5)	4729	22·8% (19·9–26·0)	19·4% (16·4–22·2)	4·2% (3·1–5·9)	5492	17·2% (14·9–19·9)	14·6% (12·3–17·2)	3·0% (2·2–4·0)
Mauritania	915	30·3% (25·2–37)	27·7% (23·1–34·7)	3·5% (2·0–6·2)	1040	18·0% (14·7–22·2)	15·5% (12·6–19·8)	2·6% (1·4–4·6)	1189	13·2% (10·3–16·6)	11·6% (8·9–14·8)	1·7% (0·8–3·2)
Mozambique	6544	42·9% (33·1–50·8)	34·3% (25·7–43·4)	11·7% (6·6–20·3)	7599	28·6% (21·0–36·5)	20·8% (14·6–28·4)	9·6% (4·9–17·3)	8562	22·1% (16·3–28·6)	16·1% (11·6–23·1)	6·7% (3·1–13·2)
Namibia	542	24·1% (19·0–32·5)	19·2% (15·0–28·0)	5·4% (3·7–13·7)	571	14·7% (11·2–23·1)	9·9% (7·3–17·7)	5·0% (3·4–11·2)	644	10·0% (7·7–18·2)	7·1% (5·0–14·9)	2·8% (1·9–6·1)
Niger	4509	21·2% (18·8–23·7)	20·2% (17·9–22·6)	1·2% (0·6–2·5)	5574	9·0% (7·8–10·5)	8·3% (7·2–9·9)	0·7% (0·3–1·6)	6778	6·3% (5·3–7·7)	5·9% (5·0–7·1)	0·4% (0·2–1·0)
Nigeria	40014	23·5% (21·9–25·8)	21·5% (19·8–23·7)	2·7% (2·2–3·6)	46384	13·1% (11·9–14·2)	11·1% (10·1–12·2)	2·1% (1·7–2·9)	52944	7·7% (6·7–8·9)	6·7% (5·9–7·9)	1·1% (0·8–1·7)
Rwanda	2225	2·8% (2·0–3·6)	0·5% (0·3–1·0)	2·2% (1·6–2·9)	2510	2·0% (1·5–2·8)	0·2% (0·1–0·5)	1·8% (1·3–2·6)	2770	1·1% (0·7–1·4)	0·1% (0·1–0·3)	0·9% (0·6–1·3)
Senegal	3426	21·2% (18·9–23·9)	19·1% (17·2–21·8)	3·1% (2·1–5·8)	3958	11·0% (9·3–13·5)	9·1% (7·5–10·4)	2·2% (1·4–4·5)	4592	7·6% (6·3–9·2)	6·1% (5·2–7·3)	1·4% (0·9–2·9)
Sierra Leone	1540	30·1% (25·3–36·5)	13·5% (7·0–21·4)	21·5% (17·7–25·9)	1717	16·9% (13·2–21·5)	3·8% (1·9–7·9)	13·3% (10·3–17·1)	1858	14·9% (11·3–19·5)	2·7% (1·2–5·5)	12·3% (9·4–17·0)
Somalia	2561	23·0% (17·4–32·5)	19·8% (14·0–26·0)	4·0% (1·6–10·8)	2911	14·1% (9·7–21·7)	10·7% (7·3–15·3)	3·4% (1·2–9·6)	3265	10·0% (6·8–15·2)	8·0% (5·3–11·6)	2·1% (0·6–6·5)
South Africa	9471	14·5% (10·8–19·4)	11·6% (8·4–16·5)	3·1% (1·8–6·6)	10170	9·0% (6·4–13·5)	6·1% (4·4–10·3)	2·8% (1·6–6·2)	11076	6·4% (4·7–11·4)	4·6% (3·1–8·3)	1·8% (1·0–5·0)
South Sudan	2235	19·0% (15·9–22)	9·8% (7·1–12·9)	10·4% (8·6–12·5)	2480	15·0% (12·9–17·4)	4·8% (3·2–7·1)	10·5% (8·5–12·4)	2553	10·2% (8·3–13·2)	3·4% (2·2–6·0)	7·0% (5·6–8·6)
Sudan	8285	31·3% (24·7–38·5)	20·1% (14·4–28·2)	14·4% (9·3–20·3)	9127	22·4% (16·3–29·8)	10·8% (7·2–17·3)	12·6% (7·7–19·0)	9906	15·6% (11·4–22·0)	7·5% (4·5–13·1)	8·5% (5·3–13·1)
Tanzania	12124	25·0% (19·8–30·1)	17·6% (13·7–21·8)	8·3% (5·9–11·6)	14381	16·6% (13·4–20·9)	9·5% (7·2–12·4)	7·6% (5·5–11·5)	16448	11·9% (9·4–15·4)	7·1% (5·2–10·1)	5·0% (3·5–7·4)
Togo	1578	23·0% (20·6–25·8)	20·8% (18·3–23·4)	2·9% (2·3–3·7)	1818	7·3% (6·4–8·7)	6·3% (5·4–7·7)	1·0% (0·8–1·5)	2011	6·1% (5·4–7·2)	5·2% (4·6–6·3)	0·9% (0·7–1·1)
Uganda	9930	19·0% (14·2–28·5)	8·2% (2·9–17·5)	11·6% (10·2–13·3)	11642	14·1% (11·4–20·8)	4·1v (1·2–11·3)	10·6% (9·3–11·9)	13633	7·3% (5·5–11·8)	2·2% (0·6–6·6)	5·1% (4·5–5·8)
Zambia	3798	36·3% (32·6–39·4)	27·3% (23·6–30·3)	14·0% (11·1–17·0)	4406	24·8% (21·6–28·9)	14·5% (12·4–18·0)	11·7% (9·5–14·6)	4950	15·6% (13·4–18·6)	9·9% (8·1–12·6)	6·4% (4·9–8·3)
Zimbabwe	3249	22·5% (20·2–24·6)	17·7% (15·6–20·0)	6·1% (5·1–7·3)	3578	11·9% (10·4–13·3)	7·5% (6·3–8·8)	4·8% (3·8–6·0)	4085	6·3% (5·5–7·4)	4·2% (3·6–5·2)	2·1% (1·6–2·8)
Total	222910	23·0% (22·1–24·1)	17·4% (16·5–18·5)	7·1% (6·5–7·6)	255001	14·5% (13·8–15·3)	9·1% (8·6–9·9)	6·0% (5·7–6·6)	287597	9·6% (9·1–10·2)	6·2% (5·7–6·7)	3·7% (3·4–4·0)

Table 3: Total number of school-aged children and population-adjusted prevalence for each infectious species in sub-Saharan Africa by year

	2010					2019				
	Population (in 1000s)	Prevalence <10%	Prevalence 10–50%	Prevalence >50%	Number of treatments (in 1000s)	Population (in 1000s)	Prevalence <10%	Prevalence 10–50%	Prevalence >50%	Number of treatments (in 1000s)
Angola	5321	1681 (1340–2451)	2087 (1551–2567)	1463 (649–2148)	3078 (2555–3441)	7721	4749 (3813–6052)	2220 (1285–2803)	472 (175–1570)	3226 (2891–3908)
Benin	2366	448 (324–596)	1168 (982–1327)	727 (600–960)	1465 (1391–1592)	3037	1941 (1659–2118)	913 (746–1175)	162 (111–254)	1268 (1224–1339)
Botswana	407	280 (216–334)	98 (57–139)	29 (14–59)	171 (156–195)	474	414 (365–447)	49 (24–88)	8 (2–28)	172 (164–189)
Burkina Faso	4444	2350 (1987–2745)	1662 (1369–1913)	425 (290–656)	2037 (1910–2203)	5900	5324 (4964–5494)	533 (378–857)	40 (20–100)	2084 (2046–2152)
Burundi	2256	1972 (1781–2074)	253 (161–414)	30 (11–87)	816 (792–869)	3211	3114 (3021–3158)	94 (49–187)	4 (0–15)	1089 (1080–1106)
Cameroon	5191	3149 (2849–3424)	1544 (1283–1870)	472 (364–646)	2303 (2217–2405)	6746	5841 (5570–6016)	803 (633–1073)	84 (48–153)	2434 (2397–2500)
Central African Republic	1204	267 (145–425)	417 (312–538)	517 (354–714)	819 (717–933)	1369	543 (369–754)	486 (359–597)	321 (196–532)	752 (659–880)
Chad	3361	816 (603–994)	1238 (1079–1412)	1305 (1120–1507)	2196 (2081–2315)	4514	2360 (2144–2542)	1526 (1377–1684)	637 (504–771)	2181 (2089–2276)
Congo	1008	802 (710–864)	161 (97–251)	34 (20–70)	382 (367–408)	1362	1286 (1231–1310)	55 (37–108)	6 (2–15)	464 (457–475)
Côte d'Ivoire	5228	2429 (2119–2675)	2027 (1783–2338)	747 (655–886)	2569 (2502–2671)	6341	4726 (4490–4907)	1297 (1147–1511)	281 (224–351)	2510 (2460–2569)
Democratic Republic of the Congo	18004	8232 (7512–8911)	6340 (5767–6918)	3433 (2985–3967)	9361 (9019–9730)	25684	18645 (17781–19445)	5746 (5037–6409)	1298 (1013–1667)	10369 (10131–10700)
Djibouti	165	95 (19–154)	42 (3–98)	8 (0–102)	68 (53–126)	169	146 (51–162)	15 (0–90)	1 (0–58)	57 (54–99)
Equatorial Guinea	281	239 (202–256)	25 (10–55)	1 (0–12)	94 (91–105)	414	382 (356–391)	11 (2–33)	0 (0–5)	133 (131–140)
Eritrea	1184	965 (879–1039)	187 (128–256)	26 (11–54)	443 (423–470)	1572	1490 (1429–1528)	71 (36–113)	5 (1–21)	537 (529–558)
Eswatini	269	241 (223–253)	26 (14–44)	1 (0–3)	95 (92–98)	283	278 (270–281)	5 (2–13)	0 (0–1)	95 (95–97)
Ethiopia	22766	13873 (10920–16084)	6418 (5058–8112)	2456 (1511–4306)	10303 (9504–11765)	26358	21953 (19279–23325)	3602 (2739–5375)	738 (416–1615)	9889 (9540–10712)
Gabon	372	189 (96–260)	136 (66–220)	41 (17–118)	171 (150–225)	506	390 (220–453)	84 (34–232)	14 (2–130)	190 (175–277)
Gambia	457	331 (276–352)	83 (65–138)	26 (16–36)	178 (172–189)	606	540 (524–554)	41 (30–55)	3 (1–10)	204 (201–209)
Ghana	6035	2276 (1836–2699)	2613 (2267–2985)	988 (742–1280)	3051 (2865–3249)	7234	5306 (4761–5717)	1555 (1179–1988)	177 (110–348)	2737 (2640–2885)
Guinea	3053	793 (600–1010)	802 (598–1031)	1382 (1136–1620)	2053 (1893–2182)	3697	1379 (1041–1680)	1165 (960–1408)	1068 (811–1317)	2112 (1956–2266)
Guinea-Bissau	420	262 (102–318)	110 (72–214)	36 (14–157)	182 (162–269)	544	461 (295–502)	66 (29–200)	9 (2–96)	195 (185–256)
Kenya	10978	6689 (4435–7841)	3188 (2312–4384)	1024 (667–2319)	4868 (4483–5905)	13192	11121 (9482–11814)	1716 (1157–2886)	283 (141–1037)	4849 (4659–5448)
Lesotho	422	375 (227–418)	42 (4–132)	4 (0–64)	151 (142–204)	414	404 (318–413)	10 (1–80)	0 (0–21)	140 (138–165)

(Table 4 continues on next page)

(Continued from previous page)

	2010					2019				
	Population (in 1000s)	Prevalence <10%	Prevalence 10–50%	Prevalence >50%	Number of treatments (in 1000s)	Population (in 1000s)	Prevalence <10%	Prevalence 10–50%	Prevalence >50%	Number of treatments (in 1000s)
Liberia	982	163 (136–216)	383 (310–494)	401 (285–487)	650 (587–696)	1237	483 (357–614)	510 (387–651)	205 (144–306)	623 (577–687)
Madagascar	5674	..	..	..	..	6838	2411 (1595–3423)	1930 (1250–2310)	2073 (1336–3062)	3904 (2684–4905)
Malawi	4200	758 (638–910)	2203 (2070–2360)	1231 (1076–1381)	2590 (2502–2676)	5421	3643 (3443–3817)	1591 (1436–1785)	181 (127–243)	2194 (2146–2251)
Mali	3918	1039 (913–1184)	1425 (1262–1648)	1456 (1240–1649)	2517 (2398–2623)	5490	3195 (2881–3471)	1688 (1419–1941)	604 (441–831)	2519 (2394–2660)
Mauritania	915	325 (220–432)	347 (269–441)	232 (176–307)	515 (477–572)	1185	795 (704–870)	288 (237–377)	89 (59–135)	500 (476–534)
Mozambique	6544	1425 (847–2081)	2273 (1930–2689)	2696 (1881–3364)	4296 (3787–4715)	8562	4046 (3187–4926)	2901 (2397–3460)	1384 (872–2090)	4191 (3806–4644)
Namibia	542	193 (154–268)	235 (195–283)	83 (56–151)	275 (252–313)	644	450 (369–499)	149 (113–223)	22 (12–90)	252 (240–296)
Niger	4509	2151 (1944–2429)	1705 (1490–1905)	642 (518–816)	2217 (2125–2329)	6775	5614 (5318–5852)	1035 (813–1312)	117 (80–197)	2512 (2459–2589)
Nigeria	40014	17584 (16276–18843)	15480 (14585–16371)	6777 (6004–7980)	20376 (19828–21185)	52943	41520 (40188–42811)	9734 (8692–10646)	1394 (1067–2162)	20129 (19772–20722)
Rwanda	2225	2082 (2019–2134)	137 (90–202)	5 (0–19)	768 (757–785)	2770	2729 (2686–2753)	41 (16–84)	0 (0–6)	931 (926–938)
Senegal	3426	1677 (1398–1857)	1031 (892–1332)	555 (480–657)	1638 (1571–1718)	4592	3507 (3304–3653)	717 (604–895)	155 (108–217)	1685 (1643–1751)
Sierra Leone	1540	542 (340–652)	470 (367–632)	418 (323–542)	830 (774–910)	1858	1085 (861–1205)	449 (373–649)	177 (102–284)	768 (718–841)
Somalia	2561	1164 (878–1442)	861 (639–1049)	447 (278–737)	1269 (1148–1464)	3265	2328 (1938–2626)	668 (455–983)	166 (71–352)	1283 (1193–1427)
South Africa	9471	6237 (5635–6907)	2164 (1750–2513)	970 (573–1501)	4135 (3834–4478)	11075	9163 (8295–9661)	1471 (1101–1886)	318 (184–940)	4120 (3968–4522)
South Sudan	2235	1223 (1120–1353)	709 (632–783)	290 (208–377)	1060 (1000–1112)	2553	1882 (1731–1980)	539 (452–634)	132 (82–205)	1028 (990–1088)
Sudan	8285	3231 (2550–3959)	2744 (2355–3184)	2276 (1635–3133)	4740 (4326–5242)	9906	6256 (5329–7130)	2568 (1968–3041)	1044 (587–1735)	4431 (4102–4881)
Tanzania	12124	5119 (4313–6159)	4530 (4006–5029)	2264 (1536–3072)	6296 (5750–6797)	16448	11180 (9998–12220)	4110 (3321–4909)	992 (644–1671)	6794 (6455–7303)
Togo	1578	640 (505–749)	668 (574–808)	242 (196–302)	794 (760–832)	2011	1643 (1567–1699)	316 (256–388)	26 (15–52)	732 (719–753)
Uganda	9930	5023 (3598–6191)	3731 (2967–4461)	1133 (720–2089)	4688 (4315–5430)	13633	10923 (9425–11673)	2347 (1738–3370)	321 (195–898)	5160 (4994–5672)
Zambia	3798	970 (828–1103)	1617 (1420–1794)	1212 (1021–1397)	2345 (2243–2460)	4950	2841 (2577–3125)	1722 (1447–1981)	374 (239–596)	2187 (2082–2322)
Zimbabwe	3249	1409 (1249–1597)	1362 (1202–1507)	478 (391–570)	1627 (1568–1691)	4084	3374 (3239–3473)	649 (558–778)	61 (43–87)	1511 (1488–1548)
Total	222910	101488 (97243–105275)	74985 (72128–77284)	39296 (36942–42021)	110637 (109062–112729)	287585	209010 (205180–212177)	55987 (53475–58957)	13981 (12495–16102)	111632 (110455–113185)

Table 4: **Population at risk of schistosomiasis and treatment needs for school-aged children in sub-Saharan Africa**

analysis. According to our estimates, in 2010, approximately 111 million doses of praziquantel were required for a total of 223 million school-aged children living in sub-Saharan Africa. The required number of tablets varies for each child, as praziquantel is administered according to a child's weight (or height), with a recommended dose of 40 mg/kg of bodyweight. These estimates increased in 2019 to 112 million doses of praziquantel for 288 million school-aged children. The need of praziquantel in the study is based on the treatment of the estimated number of infected people through targeted treatment. However, from an implementation perspective, the need of praziquantel is much higher given that preventive chemotherapy is recommended for the treament of all at-risk children (infected or not) leaving in the adminstrative unit target for treatment. Schistosomiasis prevalence across sub-Saharan Africa has decreased from 23·0% in 2000–10 to 9·6% in 2015–19; however, the population of school-aged children has grown considerably, leading to a slight increase in preventive chemotherapy needs when considering existing WHO guidelines.[21] The 2015 estimates by Lai and colleagues[13] were 122 million doses for a population of 228 million school-aged children in 2012. Considering the population growth and the schistosomiasis prevalence, Lai and colleagues'[13] estimates are consistent with the estimates presented in this Article.

The geostatistical models suggested an increased *S haematobium* and *S mansoni* risk in areas located in close proximity to freshwater bodies. Such habitats are required to complete the schistosomiasis lifecycle, which involves an intermediate host snail. The parasites require optimal environmental conditions to survive; extreme humidity or high temperatures are detrimental for survival. In our study, we had a smaller number of statistically significant climatic predictors than Lai and colleagues,[13] most likely because of the effect of interventions, which blur the effect of climatic factors on disease transmission.

Improved water and sanitation in the general population are associated with a lower risk of schistosomiasis and are considered as supplementary strategies in control and elimination programmes.[24,25] In our study, high coverage of improved sanitation was associated with lower risk of infection for *S haematobium* and *S mansoni*. Reports from WHO suggested that sub-Saharan African countries in 2015 had a coverage of basic sanitation services below 50%, apart from South Africa and Botswana (50–75% coverage).[26] Improvements in sanitation comparing the situation in 2000–10 with 2011–19 are relatively modest. In fact, almost half of the countries had improvement rates below 20% at the national level. In Ethiopia, the proportion of households with improved sanitation has increased by almost 80%, from 15% in 2005 to 28% in 2015, although admittedly from a low starting point. Angola, Benin, Burkina Faso, Guinea, Guinea-Bissau, Mauritania, and Niger follow, with improvement rates varying from 42% (Niger) to 31% (Guinea). These countries

also showed high *Schistosoma* species prevalence reductions. However, in Gambia, Nigeria, South Sudan, and Zimbabwe, the proportion of households with improved sanitation decreased at the national level when comparing prevalence in 2000–10 with 2011–14 and 2015–19, yet we observed high *Schistosoma* species reduction rates in these countries.

Our model-based estimates of the geographical patterns of *S haematobium* prevalence in 2000–10 showed similarities to those reported by Lai and colleagues.[13] Countries such as Guinea and Namibia initiated cross-sectional surveys after 2011, which enabled us to obtain more accurate estimates. For 2011–19, the predictions for *S haematobium* prevalence showed a change in the geographical distribution across all of the included sub-Saharan African countries due to a major reduction of existing disease clusters in most of these countries. The only remaining areas with prevalence above 50% were settings in Senegal (around Kénièba near to the border with Mali), in Guinea (around Touba near the Guinea-Bissauan and Senegalese border, and around Banora near to the Malian border), and in the Democratic Republic of the Congo in the southwestern-most bank of the Congo River. By comparison with prevalence estimates for 2000–10, areas considered at high risk are much smaller in size, with prevalence at moderate levels (between 10% and 50%). The majority of high prevalence (>50%) settings can be found in the vicinity of large rivers (eg, the Niger River) or lakes (eg, Lake Victoria). The geographical pattern of *S mansoni* for 2000–10 is in accordance with the pattern observed by Lai and colleagues,[13] with the exception of Djibouti, Mozambique, and South Africa, for which we had no or very sparse data. During 2015–19, estimates showed a decline in countries that were previously known to be endemic. The reduction is most noticeable in Cameroon, the Democratic Republic of the Congo, and Ethiopia, where high-risk settings identified in 2000–10 have considerably decreased in size. Existing high-risk areas in west Africa still persist, although they have slightly decreased in size. In central and east Africa, *S mansoni* has decreased considerably across all countries; a few high-risk areas with infection prevalence among school-aged children above 50% are located in close proximity to major rivers or lakes. In Angola, a major high-risk area is noticeable in the northwestern region in a large area around Uige.

The main limitation in our study is the scarcity of more granular data before 2010, which might have been caused by purposeful selection of sites for surveys in known endemic areas at that time. The prevalence during 2000–10 could have been overestimated because of this bias, leading to an overestimation of the effect of preventive chemotherapy. The blank areas (scarce or no observed data with low predicted prevalence) might have been of low or no prevalence historically. The large number of surveys included in the analysis, obtained from heterogeneous

sampling designs, made assessing their risk of bias difficult. Prevalence values were based mainly on urine filtration and reagent strip testing for *S haematobium* and on Kato-Katz stool examinations for *S mansoni*. Although most of the surveys used the same diagnostic technique, bias might have been introduced by differences in the sampling efforts (eg, single strip for urine sample versus multiple samples). Unfortunately, the sampling effort is not always reported; therefore, it is not possible to adjust the estimates for this source of heterogeneity. In most cases urine filtration reagent strip testing or Kato-Katz thick smear examinations were done on one specimen; however, some data sources used two or three specimens from different days and calculated the mean prevalence.

Our analysis is based on survey data obtained through school-based sampling, however, information on school attendance was not available to adjust the models for possible selection bias in locations where school attendance was low. Most of the data were aggregated over different age groups for school-aged children, thus we could not obtain age-specific risk estimates. Bias might occur when the age distribution in the survey population differs across locations as different age groups might have different infection risks. Furthermore, long-term data are scarce as most countries started doing national surveys only after 2011. This limitation did not allow for a full spatiotemporal assessment of disease prevalence similar to the works of Blangiardo and colleagues,[19] and Chammartin and colleagues,[20] who analysed periodic data in time over the same set of locations. The most prominent examples in our study were Chad, Mozambique, and Sudan, which had available data only after 2011, showing a high prevalence of schistosomiasis. The spatiotemporal models for these countries predicted higher disease prevalence during 2015–19 than 2000–10. This outcome might be an artefact of the imposed temporal structure, where observed data from the period 2015–19 only partially inform the predictions during 2000–10. Data were scarce in Central African Republic, Djibouti, and Equatorial Guinea; therefore, estimates for these countries might not be accurate. Our estimates of schistosomiasis prevalence assume that the probability of infection with one species does not affect the infection probability of the other species, an assumption also made in previous studies.[13,27]

In accordance with WHO guidelines, many countries in sub-Saharan Africa scaled up preventive chemotherapy in an effort to control and eliminate schistosomiasis. Our model-based predictions confirm that schistosomiasis decreased significantly during the period of intensified control and several countries (eg, Burundi, Eritrea, Eswatini, Gambia, Lesotho, and Rwanda) could already be in a position to start considering elimination strategies. Our observations suggest that it is feasible to get to a low prevalence of, and perhaps eliminate, schistosomiasis as a public health problem, as policy makers and WHO and the national programmes further amplify their efforts for disease control. Large-scale preventive chemotherapy targeting all at-risk groups coupled with social and economic development (eg, improvements in sanitation), snail control and information, education, and communication strategies will enable further decline in disease transmission and contribute to elimination. Unfortunately, the COVID-19 pandemic has delayed or disrupted altogether preventive chemotherapy treatment in 2020. Hence, there is considerable concern that the progress made in schistosomiasis control over the past several years is reversing,[28,29] which requires close monitoring and surveillance.

References
1 McManus DP, Dunne DW, Sacko M, Utzinger J, Vennervald BJ, Zhou XN. Schistosomiasis. *Nat Rev Dis Primers* 2018; **4:** 13.
2 Kyu HH, Abate D, Abate KH, et al. Global, regional, and national disability-adjusted life-years (DALYs) for 359 diseases and injuries and healthy life expectancy (HALE) for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet* 2018; **392:** 1859–922.
3 WHO. Schistosomiasis and soil-transmitted helminthiases: numbers of people treated in 2018. *Wkly Epidemiol Rec* 2018; **94:** 601–12.
4 WHO. Accelerating work to overcome the global impact of neglected tropical diseases: a roadmap for implementation: executive summary. Geneva: WHO, 2012.
5 Tchuem Tchuenté LA, Rollinson D, Stothard JR, Molyneux D. Moving from control to elimination of schistosomiasis in sub-Saharan Africa: time to change and adapt strategies. *Infect Dis Poverty* 2017; **6:** 42.
6 Grimes JET, Croll D, Harrison WE, Utzinger J, Freeman MC, Templeton MR. The relationship between water, sanitation and schistosomiasis: a systematic review and meta-analysis. *PLoS Negl Trop Dis* 2014; **8:** e3296.

7   Lo NC, Addiss DG, Hotez PJ, et al. A call to strengthen the global strategy against schistosomiasis and soil-transmitted helminthiasis: the time is now. *Lancet Infect Dis* 2017; **17:** e64–69.

8   King CH, Sutherland LJ, Bertsch D. Systematic review and meta-analysis of the impact of chemical-based mollusciciding for control of *Schistosoma mansoni* and *S. haematobium* transmission. *PLoS Negl Trop Dis* 2015; **9:** e0004290.

9   Sokolow SH, Wood CL, Jones IJ, et al. Global assessment of schistosomiasis control over the past century shows targeting the snail intermediate host works best. *PLoS Negl Trop Dis* 2016; **10:** e0004794.

10 Lai YS, Biedermann P, Ekpo UF, et al. Spatial distribution of schistosomiasis and treatment needs in sub-Saharan Africa: a systematic review and geostatistical analysis. *Lancet Infect Dis* 2015; **15:** 927–40.

11 Hürlimann E, Schur N, Boutsika K, et al. Toward an open-access global database for mapping, control, and surveillance of neglected tropical diseases. *PLoS Negl Trop Dis* 2011; **5:** e1404.

12 WHO. Expanded special project for elimination of neglected tropical diseases. 2017. https://www.afro.who.int/health-topics/expanded-special-project-elimination-neglected-tropical-disease#:~:text=The%20 Expanded%20Special%20Project%20for,to%20help%20them%20 accelerate%20the (accessed Sept 15, 2021).

13 Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Ann Intern Med* 2009; **151:** 264–69.

14 Hanks EM, Schliep EM, Hooten MB, Hoeting JA. Restricted spatial regression in practice: geostatistical models, confounding, and robustness under model misspecification. *Environmetrics* 2015; **26:** 243–54.

15 Giardina F, Sogoba N, Vounatsou P. Bayesian variable selection in semi-parametric and nonstationary geostatistical models: an application to mapping malaria risk in Mali. In: Lawson AB, Banerjee S, Haining RP, Ugarte MD, eds. Handbook of spatial epidemiology. Boca Raton: CRC Press, 2016: 399–416.

16 Blangiardo M, Cameletti M, Baio G, Rue H. Spatial and spatio-temporal models with R-INLA. *Spat Spatio-Temporal Epidemiol* 2013; **4:** 33–49.

17 Chammartin F, Guimarães LH, Scholte RGC, Bavia ME, Utzinger J, Vounatsou P. Spatio-temporal distribution of soil-transmitted helminth infections in Brazil. *Parasit Vectors* 2014; **7:** 440.

18 Gelman A, Hwang J, Vehtari A. Understanding predictive information criteria for Bayesian models. *Stat Comput* 2014; **24:** 997–1016.

19 WHO. Preventive chemotherapy in human helminthiasis: coordinated use of anthelminthic drugs in control interventions: a manual for health professionals and programme managers. Geneva: WHO, 2006.

20 WHO. Preventive chemotherapy (PC) by country. 2018. https://www.who.int/neglected_diseases/preventive_chemotherapy/sch/en/ (accessed Sept 15, 2021).

21 Held L, Schrödle B, Rue H. Posterior and cross-validatory predictive checks: a comparison of MCMC and INLA. In: Kneib T, Tutz G, eds. Statistical modelling and regression structures. Berlin: Springer, 2010: 91–110.

22 Coulibaly JT, N'Gbesso YK, Knopp S, Keiser J, N'Goran EK, Utzinger J. Efficacy and safety of praziquantel in preschool-aged children in an area co-endemic for *Schistosoma mansoni* and *S. haematobium*. *PLoS Negl Trop Dis* 2012; **6:** e1917.

23 Garba A, Lamine MS, Barkiré N, et al. Efficacy and safety of two closely spaced doses of praziquantel against *Schistosoma haematobium* and *S. mansoni* and re-infection patterns in school-aged children in Niger. *Acta Trop* 2013; **128:** 334–44.

24 Grimes JET, Croll D, Harrison WE, Utzinger J, Freeman MC, Templeton MR. The roles of water, sanitation and hygiene in reducing schistosomiasis: a review. *Parasit Vectors* 2015; **8:** 156.

25 French MD, Evans D, Fleming FM, et al. Schistosomiasis in Africa: improving strategies for long-term and sustainable morbidity control. *PLoS Negl Trop Dis* 2018; **12:** e0006484.

26 UN. UN-Water global analysis and assessment of sanitation and drinking water (GLAAS) 2017 report: financing universal water, sanitation and hygiene under the Sustainable Development Goals. April 12, 2017. https://www.unwater.org/publications/un-water-glaas-2017-financing-universal-water-sanitation-hygiene-sustainable-development-goals/ (accessed Sept 15, 2021).

27 Chammartin F, Houngbedji CA, Hürlimann E, et al. Bayesian risk mapping and model-based estimation of *Schistosoma haematobium-Schistosoma mansoni* co-distribution in Côte d'Ivoire. *PLoS Negl Trop Dis* 2014; **8:** e3407.

28 Ehrenberg JP, Zhou XN, Fontes G, Rocha EMM, Tanner M, Utzinger J. Strategies supporting the prevention and control of neglected tropical diseases during and beyond the COVID-19 pandemic. *Infect Dis Poverty* 2020; **9:** 86.

29 Toor J, Adams ER, Aliee M, et al. Predicted impact of COVID-19 on neglected tropical disease programs and the opportunity for innovation. *Clin Infect Dis* 2021; **72:** 1463–66.

30 International Food Policy Research Institute. HarvestChoice. 2011. http://harvestchoice.org/node/4996 (accessed Sept 15, 2021).

31 Lindgren F, Rue H, Lindström J. An explicit link between Gaussian fields and Gaussian Markov random fields: the stochastic partial differential equation approach. *J R Stat Soc Series B Stat Methodol* 2011; **73:** 423–98.

32 Willmott CJ, Matsuura K. Advantages of the mean absolute error (MAE) over the root mean square error (RMSE) in assessing average model performance. *Clim Res* 2005; **30:** 79–82.

33 Rue H, Martino S, Chopin N. Approximate Bayesian inference for latent Gaussian models by using integrated nested Laplace approximations. *J R Stat Soc Series B Stat Methodol* 2009; **71:** 319–92.

34 Gorelick N, Hancherb M, Dixon M, et al. Google Earth Engine: planetary-scale geospatial analysis for everyone. *Remote Sens Environ* 2017; **202:** 18–27.