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REVIEW

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Systematic review on the cost of seasonal malaria chemoprevention (SMC)

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Abstract

Background Implemented in 17 countries to date, seasonal malaria chemoprevention (SMC) is a recommended strategy to prevent childhood malaria in areas with seasonal transmission of *P. falciparum* through monthly administration of antimalarial medicines. Understanding the costs and resource requirements of SMC delivery is necessary for effective planning and resource allocation. This systematic literature review aims to assess the evidence on the cost and cost-effectiveness of SMC delivery.

Methods Following PRISMA guidelines, five databases were systematically reviewed to identify evidence on SMC costs and cost-effectiveness published between 2012 and 2023. Studies with defined costing methodologies and cost output measures were included, excluding those relying solely on mathematical modeling. Two reviewers assessed each study for eligibility and extracted cost data, which were adjusted for inflation. Quality assessment was completed using the CHEERS checklist.

Results Six costing studies were identified spanning nine countries. Four studies examined costs during an SMC pilot or introduction, one during scale-up, and one costed newly established SMC campaigns through a multi-country project. Costs were examined at country level with the financial costs per child receiving a full course of SMC ranging from $1.71 to $12.46, while economic costs per child ranged from $2.11 to $29.06. Four studies included a cost effectiveness analysis with incremental cost-effectiveness ratios (ICERs) per clinical malaria case averted ranging from $5.41 to $138.03; ICER per disability-adjusted life year (DALY) averted from $24.51 to $182.88; and ICER per death averted from $688.86 to $18,418.81. Differences in cost estimates stemmed from different factors including variations in cost ingredients, scale of the intervention, and study perspectives.

Discussion The level of detail for reporting SMC costs and cost categories varied greatly by study as did the scale of intervention, limiting comparability as well as an understanding of the complete costs and resource requirements for SMC implementation. Cost evidence is not from mature programs but from pilots or relatively new campaigns. Costs incurred by households and costs of the integrated delivery of SMC with other health interventions were often overlooked. Adopting a standardized costing approach for mature SMC programmes could provide a better understanding of resource requirements and costs while enhancing study comparability across settings, better informing future resource allocation and improving efficiency.

Keywords SMC, Seasonal malaria chemoprevention, Costing, Cost-effectiveness, Malaria, Delivery costs

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Background

Malaria remains a significant global health threat as the sixth-leading cause of death globally. The malaria burden is especially concentrated in the World Health Organization (WHO) African region which in 2022 accounted for

94% of 249 million total malaria cases and 95% of 608,000 malaria deaths globally. Children under five years of age accounted for 78% of those malaria deaths in the region [1]. Malaria prevention technologies continue to evolve with several new strategies for vector control, preventive chemotherapy, mass drug administration, and vaccines. It is important for countries to understand the economic implications of malaria preventive technologies. However, as domestic and international funding for malaria is plateauing, it is crucial for decision-makers to have the best possible evidence to make decisions on the most effective and efficient strategies for their setting [2]. Therefore, it is important for countries to understand the economic implications of malaria preventive technologies.

Seasonal Malaria Chemoprevention (SMC) is considered a cost-effective intervention for malaria prevention [3, 4]. SMC consists of giving children of sulfadoxine–pyrimethamine (SP) plus amodiaquine (AQ) at 28-day intervals, beginning at the start of the high transmission season, and continuing for 3–5 monthly cycles, depending on the local context and disease burden. This maintains sufficiently high antimalarial drug concentrations in the blood throughout the period of greatest risk [4–8]. Since 2012, when SMC was recommended by the WHO for children at high risk of severe malaria living in areas with seasonal transmission, 17 countries have adopted SMC [1]. To date, the average number of children treated with at least one dose of SMC increased from about 0.2 million in 2012 to 49.4 million in 2022, with over half of those reached (25.5 million) in Nigeria [1].

Although SMC with sulfadoxine-pyrimethamine + amodiaquine (SP-AQ) has been largely focused in the Sahel subregion of sub-Saharan Africa, recent evidence demonstrates that the intervention may retain its protective effect even in regions with presumed high SP resistance, including countries such as South Sudan and Mozambique [9, 10]. Additionally, SMC has been successfully implemented in conflict settings and varying geographies [11], highlighting a versatile option for malaria prevention that can be adopted by a range of countries. Moreover, SMC continues to be scaled up and expanded, for example, including options of adding a fifth monthly cycle or extending the distribution of SMC to older children [12].

To guide resource allocation decisions for malaria, this systematic literature review sought to identify peer-reviewed evidence on the cost and cost-effectiveness of SMC. Cost and cost-effectiveness analyses are carried out to improve the value for money of healthcare investments, informing policy or decision makers on where to allocate scarce resources for greater public health impact. Cost-effectiveness studies are done as part of a complete economic evaluation with the aim of comparing the costs and corresponding quantified natural units of health outcomes (e.g. lives saved, cases averted). The review assessed the financial costs (i.e., expenditures) and economic costs (i.e., true value of resources), including costs such as unpaid volunteer distributors and/or the use of equipment associated with the delivery of SMC from both the provider and patient perspectives. The review also sought to capture details on the cost ingredients and SMC delivery methods.

Methods

Search strategy

The completed systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. Searching was initiated with "SMC" and the terms "children," "IPTi," "seasonal," "chemoprevention," "cost," "cost-effectiveness," "malaria," and related terms. The full search strategy is outlined in *Annex 1*. Academic journals and databases were reviewed over the past 11 years, from 2012, the year the WHO officially recommended SMC, to October 2023 when the search was performed, to identify peer-reviewed studies related to SMC costing and cost-effectiveness. PubMed, Embase, The Cochrane Central Register of Controlled Trials, African Journals Online (AJOL), and EconLit were searched. A comprehensive search strategy with key terms based on the study population, exposure, and outcomes of interest was developed in PubMed and adjusted to suit other databases.

Article screening and selection

Full-text articles published in English or French from January 2012 to October 2023 were eligible for inclusion, with the start year corresponding to WHO's endorsement of SMC. Studies were required to have a defined costing methodology and set of costing output measures, for example unit cost, cost per person, cost per DALY, or cost per service area. Only studies that collected primary cost data were included in the review. Studies that relied on mathematical modeling of cost data originally published by other studies were excluded. A complete description of inclusion and exclusion criteria can be found in *Annex 1*. Papers that reiterated findings from other studies already included in the review were also excluded.

Data extraction, standardization, and synthesis

Two reviewers independently conducted searches in the six listed databases. Following the removal of duplicates, the screening process was conducted at the title, abstract and full text levels by two reviewers independently using

defined criteria, and any discrepancies were resolved by consensus with a third reviewer.

The reviewers extracted relevant study data from selected studies using a predetermined template, including information on costs, cost-effectiveness, delivery methods, and associated factors. Costs and ICERs were inflated to 2023 USD to allow comparison between studies. To present the costs adjusted to a common year, delivery costs were calculated using local inflation rates for services that were subsequently converted to reflect 2023 USD, while globally purchased and priced goods such as SMC drugs and supplies as well as equipment and materials were converted using USD [13]. Findings are descriptively presented and discussed while elaborating on malaria prevention interventions and the related primary and secondary outcomes. Data are presented in tables for comparison of both the SMC delivery strategy as well as the costing studies and outcomes.

Quality assessment of the studies

The quality of the selected studies was assessed against the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) checklist [14]. The 28-item checklist was used to assess the economic evaluation studies through the online interactive form https://don-husereau.shinyapps.io/CHEERS/ summarized in Table 1 and attached as in Annex 2. The checklist describes the minimum amount of information which should be provided in each category when reporting economic evaluations.

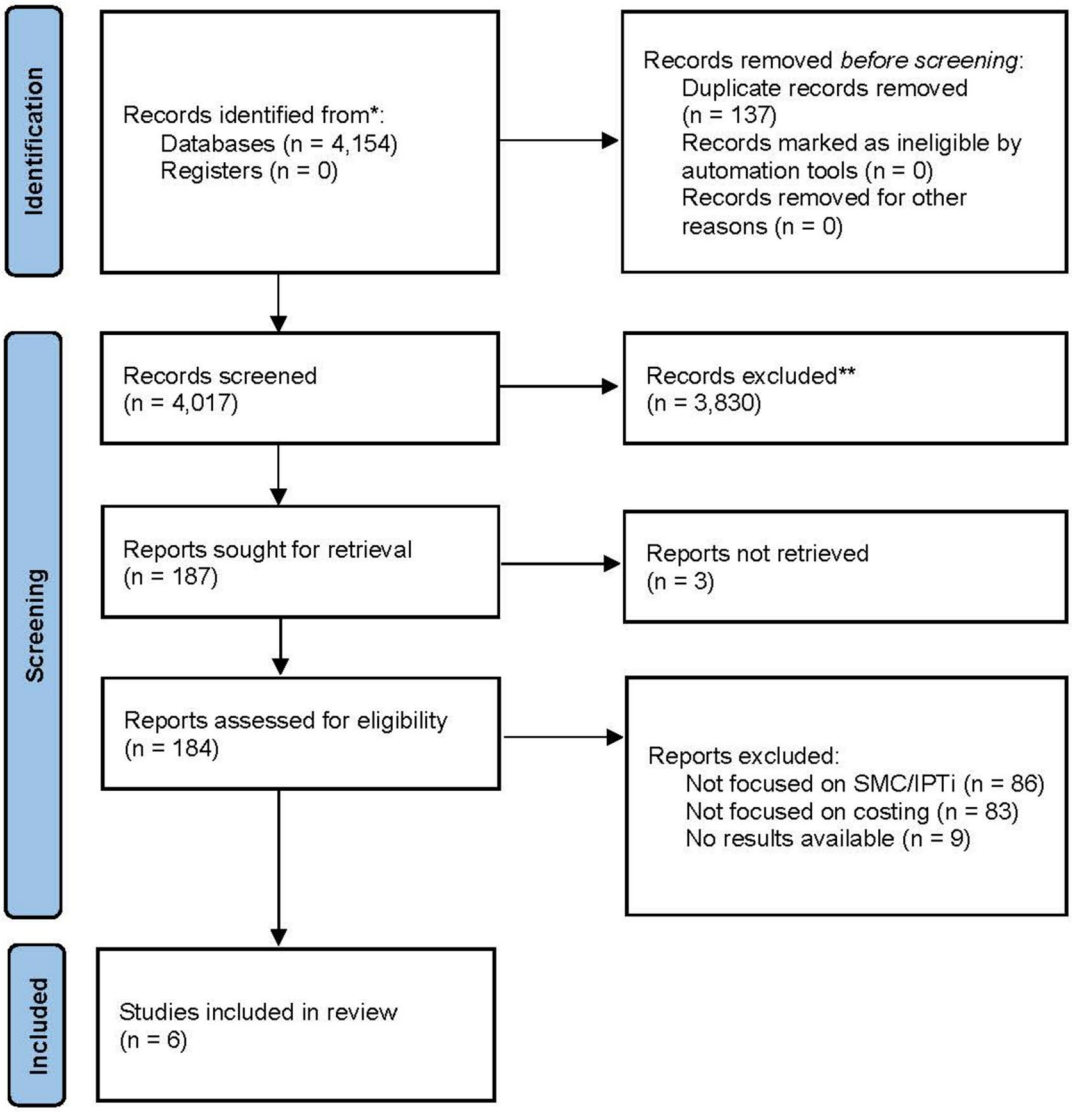
Results

Literature search

In total, six studies which included primary cost data were selected for the final analysis [3, 15–19]. The study selection process and data sources are outlined in Fig. 1. Following the initial Boolean operator search combination, 4,154 total records were obtained from PubMED, EMBASE, Cochrane Library, AJOL, and EconLit. After removing 137 duplicates, 4,017 record titles were screened according to the inclusion criteria, and 170 qualified for abstract screening.

Table 1 CHEERS checklist assessment

CHEERS checklist topics	Percentage of Articles reported (%)
Methods	
Health economic analysis plan	0
Study population	83
Setting and location	100
Comparators	100
Perspective	100
Time horizon	100
Discount rate	83
Selection of outcomes	100
Measurement of outcomes	83
Valuation of outcomes	83
Measurement and valuation of resources and costs	83
Currency, price date, and conversion	100
Rationale and description of model	50
Analytics and assumptions	100
Characterizing heterogeneity	67
Characterizing distributional effects	33
Characterizing uncertainty	83
Approach to engagement with patients and others affected by the study	50
Results	
Study parameters	83
Summary of main results	100
Effect of uncertainty	100
Effect of engagement with patients and others affected by the study	0



*Databases included PubMED (n = 2452), EMBASE (n = 1475), Cochrane (n = 223), AJOL (n = 4), EconLit (n = 0).

*Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/registers).

**If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools.

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

Fig. 1 Flow diagram of study selection process

Characteristics of identified studies

Characteristics of the six eligible studies included in this systematic review are highlighted in Table 2. Costing studies were published from 2016 to 2021 for SMC campaigns conducted from 2008 to 2016 using various SMC distribution methods. Four studies examined costs during

Table 2 Characteristics of studies included for the seasonal malaria chemoprevention (SMC) costing review

Study	Cisse et al. 2016	Pitt et al. 2017	Faye et al. 2018	Diawara et al. 2021	Nonvignon et al. 2016	Gilmartin et al. 2021
Year of SMC campaign	2008–2010	2010	2013–14	2014	2015	2016
Currency, price date, and conversion	Reported in USD, cost data was collected for the 2010 campaign only	Costs are presented in average 2010 USD exchange rate with the West African Franc (1 USD = 495 XOF(OANDA))	Costs were collected in the local currency and converted to 2014 US$ using the average exchange rate	2014 cost data are presented in 2016 Communauté Financière en Afrique (CFA) and US Conversion rate of CFA 494.17: USD 1 was assumed based on the average for August 2014 inflated to 2016 using the US Inflation Calculator	Costs were measured in Ghanaian Cedis (GHS) and pound sterling (GBP) converted to USD according to Bank of Ghana's average annual exchange rate for the year of the expenditure (US$1.00 equivalent to GHS3.74 in 2015)	Costs were estimated in 2016 USD If local currency was used, costs were converted using 2016 exchange rates, with US$1 equal to 591 XOF, 591 XAF, 8347 GNF, 260 NGN, or 43 GMD
Setting/location	SMC introduction in 3 districts over three years in central Senegal	SMC introduction in 4 districts in Senegal	16 districts in Senegal on the scale up of various combinations of preventive and curative interventions	Pilot implementation of SMC in Kita district through fixed point distribution	Pilot SMC intervention in 11 districts in northern Ghana	Burkina Faso, Chad, The Gambia, Guinea, Mali, Niger, Nigeria
Target population	~14,000 children aged 3–59 months in 2008 ~90,000 children under ten years of age in 2009 ~160,000 children under ten years of age in 2010	180,000 children aged 3 months to 10 years	2,020,597 children ages 3–120 months	~77,497 children between 3 and 59 months were forecast to receive SMC ~104,255 children received SMC (incl children older than 5 years and from bordering villages)	~148,104 children younger than 59 months	~6,960,987 children younger than 59 months
Drug regimen	3 cycles of SP + AQ, September to November in 2008 2009, and 2010	3 cycles SP + AQ	SP + AQ (cycles not specified)	4 cycles SP + AQ in August to November	4 cycles SP + AQ Study captured data for the fourth round of dosing	4 cycles SP + AQ from July to December
Distribution approach	Door to door	Door to door	Not stated	Fixed point	Door to door	Door to door (n = 6) Fixed point (n = 4) Mobile point (n = 2)

Table 2 (continued)

Study	Cisse et al. 2016	Pitt et al. 2017	Faye et al. 2018	Diawara et al. 2021	Nonvignon et al. 2016	Gilmartin et al. 2021
Number of distributors	Not stated	-CHWs administering SMC each month (mean): 831 -Average number of SMC courses administered per CHW per day (health post mean) : 46	Not stated	-Drug administration performed by 588 drug dispensers (nurses and CHWs) organized into 133 teams of 2–6 health workers each at health centers (n = 37 teams) and village fixed points (n = 96 teams) -The first dose was given by health workers, the second and third doses were given to parents to be administered at home	Not stated	Burkina Faso: 13,957 (13,105 volunteer, 852 MOH salaried) Chad: 8,029 volunteers Guinea: 2,234 volunteers Mali: 5,318 (3,552 volunteers, 1,766 MOH salaried) Niger: 3,809 volunteers Nigeria: 13,309 (11,893 volunteers, 1,416 MOH salaried) The Gambia: 582 volunteers
Data source	-Detailed information on costs was obtained from all 46 facilities that implemented SMC (45 health posts and one mission clinic)	-Data collection tools administered to four levels: the project, the district, the health post, and CHWs -Questionnaires included resource use, activities, and payments -Key informant interviews were conducted with local field coordinators and CHWs to compare the per diems paid to CHWs with what they could otherwise have earned on the SMC administration days	-Data collection occurred from Jan-Feb 2016. Cost data was obtained from the NMCP and implementing partners -Additional data sources included M&E reports and routine HMIS data	-Data sources are MCSP expense records, drug stock inventories, MoH personnel pay slip, and vehicle rental documents	-A cross-sectional survey of volunteers and caregivers participating in SMC distribution -Financial costs were obtained retrospectively from the SMC program reports and accounts of the region and district in the custody of the malaria focal persons and accounting officers	-Financial costs were obtained from accounting and budget records of implementing NGO partners and through interviews with personnel involved in program management, supervision, and distribution -Normative data on the time spent by Ministry of Health (MOH) supervisors and managers were collected through interviews in each country
Perspective and costing approach	-Provider perspective -Financial and economic costs estimates per child per month are reported	-Costs are at district level and below from a health service perspective -Both financial and economic costs are included	-Analysis was done from the health system perspective -Only financial costs considered	-Costs are presented from the provider perspective using an ingredients approach -Both financial and economic costs (recurrent and capital) are estimated for the 4 cycles of distribution	-Costing was undertaken from both a provider perspective and societal perspective -Financial and economic costs were analyzed separately	-Costs are presented from a programmatic perspective -Both financial and economic costs are included

Table 2 (continued)

Study	Cisse et al. 2016	Pitt et al. 2017	Faye et al. 2018	Diawara et al. 2021	Nonvignon et al. 2016	Gilmartin et al. 2021
Cost ingredients	Not stated	SMC drugs, drug transport/supply chain, drug administration (CHWs), supervision, CHW and head nurse training, evaluation and planning meetings, sensitization, drugs for side effects, other supplies	Personnel, training, distribution, consumables, and monitoring and evaluation (M&E). Distribution costs include all logistic costs including transport, communication, material, equipment, and other logistics costs	Planning, communication, training, drugs, personnel, equipment, and transport	Planning, social mobilization, health worker and volunteer training, dosing exercise, monitoring and supervision, data capture, pharmacovigilance, post-SMC feedback/review meeting	SMC drugs and supplies, meetings, per diem, travel, training, program management, social mobilization, volunteer opportunity costs
Integration	Not stated	Not stated	Costing study looks at SMC in combination with a scale-up package which includes bed nets, intermittent preventive treatment in pregnancy, rapid diagnostic tests, and artemisinin combination therapy	Not stated	Not stated	In Burkina Faso, Mali, and Niger, SMC was reportedly integrated with the provision of rapid diagnostic tests for malaria, malaria treatment, malnutrition screening, and referrals
Costing study assumptions and limitations	-The study's primary objective is to assess the effectiveness of SMC; a costing component was added in the last year of the trial to address questions from a WHO consultative group relating costs and safety	-Different target populations study includes children up to 10 years -Costs at national level are excluded, study includes costs of implementation at the district level and below	Costs incurred by patients and opportunity costs (e.g. time spent by volunteer CHWs) were not accounted for. Implementing partner overhead costs (including rent, utilities, and maintenance) were excluded as it was not possible to obtain this information	-The SP + AQ used for SMC in Kita were not co-blistered or pre-packed. For repackaging, 10 people were recruited for 25 days -The first dose was given by health workers, the second and third doses were given to parents to be administered at home	-Study assumed the cost of the fourth round of SMC would be the same for all cycles	-Excludes some capital costs (NGO/MOH office buildings and vehicles), start-up costs, and pharmacovigilance systems -Did not measure economic costs of households accessing SMC or treated children with secondary effects

CHW: community health workers. MoH: Ministry of Health. SPAQ: sulfadoxine-pyrimethamine (SP) plus amodiaquine (AQ) comprised a therapeutic dose of AQ (10 mg per kg per day for 3 days) combined with one dose of SP on the first day (25 mg sulfadoxine, 1.25 mg pyrimethamine) administered once per month. USD: United States Dollars

an SMC pilot or introduction [15, 16, 18, 19], one examined costs during scale-up [17], and one costed newly established SMC campaigns through a multi-country project [3]. Selected studies included results across nine countries: Burkina Faso (n = 1), Chad (n = 1), The Gambia (n = 1), Ghana (n = 1), Guinea (n = 1), Mali (n = 2), Niger (n = 1), Nigeria (n = 1), and Senegal (n = 3). Five studies included costing data on a single country while one study assessed the cost in six countries. Study populations (children targeted for SMC) ranged from 104,225 in Mali to 2,020,597 in Senegal. Four studies excluded children over five years old while two studies included children up to age ten. Costing studies were published from 2016 to 2021 for SMC campaigns conducted from 2008 to 2016 using various SMC distribution methods. These included door-to-door distribution, where community health workers, supervised by the health post, deliver SMC directly to households within a catchment area (Senegal, Ghana, Burkina Faso, Chad, The Gambia, Guinea, Mali, Niger, Nigeria); fixed point distribution, which involves delivering SMC through established locations within the routine health system (Mali, Burkina Faso, Chad, The Gambia, Guinea, Niger, Nigeria); and mobile point distribution, where SMC is temporarily distributed through health posts or community locations such as schools, churches, or open spaces (Mali, Niger). Studies included costs of either three (n = 2) or four (n = 3) monthly cycles of SMC with SP-AQ and one (n = 1) did not specify the number of cycles administered.

As our selection criteria required studies to include primary data, all studies included cost estimates, and four studies also included cost effectiveness estimates. Five of the studies included both financial and economic costs, while one included only financial costs. Two of the six studies analysed costs from a health system/service perspective, where resources required to deliver the intervention are identified and measured during implementation. Four studies presented costs from a provider perspective, a costing method which accounts for all costs incurred by the provider. One of these four also looked at the societal perspective, considering the overall resources and time which could have been allocated for other needs [20]. One study followed a programmatic perspective, and details the resources provided by non-governmental organizations and the government separately.

Costs ingredients of SMC delivery

Four of the studies [3, 16, 18, 19] provided detailed information on the cost ingredients used to calculate the cost per round or annual cost. The studies by Cisse et al. and Faye et al. did not report estimates for the cost ingredients used for their calculations, therefore Tables 3 and 4 only report the cost ingredients per country for the studies by Gilmartin et al., Diawara et al., Nonvignon et al., and Pitt et al. [3, 16, 18, 19]. After mapping the costs reported by the studies, we organized intervention and provider costs into the following categories: SMC drugs and supplies; drug transport including supply chain and vehicles; drug administration incl. personnel costs, training, travel and per diem; volunteer stipends; planning and management; equipment and materials; information, education, social mobilization; and other as shown in Tables 3 and 4. Note that studies may have costed more categories, however these were not always reported separately. These differences in categorization and reporting lead to great variability between studies. Three studies reported the costs per category whereas one study [18] only reported the cost percentages. The percentages were applied to the total financial cost and for the other studies the percentages were recalculated over the total cost.

Studies did report on their methods around annualization of capital costs, but the capital costs were not reported separately and, therefore, only financial and economic costs were distinguished. Financial costs in Table 3 include the unit costs that were actually paid for a good or service, i.e. included as a budgetary line, versus the economic costs which includes the opportunity costs of the SMC delivery [21]. Economic costs in Table 4 reflect the opportunity costs and cover the value of all resources used including those not captured in financial costs by estimating their value.

In terms of programmatic cost-drivers, drug administration costs are a large cost driver, but estimates varied greatly from 0.8 to 55.4% of the total financial costs, followed by SMC drugs and supplies 19.7–38.8%. Note that the drug administration category included a wide range of subcategories such as supervision and travel. Because certain distribution methods were only included in some studies, and each study had different target populations, evidence as to which delivery strategy or level had the highest drug administration cost was not conclusive. Training ranged from 3.9% – 11.0% of the total financial costs. Categories that are only reported by a single study include travel and per diem, equipment and materials, and volunteer stipends. Similarly, only one study reported capital costs. Studies that reported costs as "other" include examples such as NGO programme management and programme management salaries and research participation incentives. One study reported high costs on data capture (17%), which was grouped under planning & management [18]. Table 5 shows a mapping of the components identified in each study within this review. While some components (e.g., training, SMC drugs and supplies) were universally costed, others (e.g., transport, per diem and IEC) are only incorporated into some

Table 3 Financial cost for SMC delivery, percentage of total cost, cost per ingredient (converted to USD 2023)

Intervention or provider costs[1] (%) and USD	Burkina Faso (3)	Chad (3)	Gambia (Rep of The) (3)	Ghana (18)	Guinea (3)	Mali (16)	Mali (3)	Niger (3)	Nigeria (3)	Senegal (19)
Target population[2]	*1,462,033*	*573,766*	*90,925*	*148,104*	*426,278*	*104,255*	*1,461,520*	*1,210,863*	*6,960,987*	*180,000*
Number of monthly SMC cycles administered	*4*	*4*	*4*	*4*	*4*	*4*	*4*	*4*	*4*	*3*[3]
SMC drugs and supplies, incl drug transport	41.8%	42.3%	27.5%		44.1%	44.8%	55.7%	35.6%	19.8%	33.2%
	2,272,387	922,185	668,350		1,819,290	158,106	1,523,877	2,398,526	148,679	74,661
Drug administration—salaries, supervision, etc	4.6%	4.5%	3.0%	56.0%	13.0%	36.3%	3.3%	12.6%	0.8%	49.5%
	251,363	98,533	72,833	615,841	537,484	128,195	89,101	851,112	5,989	111,349
Pharmaco-vigilance, drugs for side-effects, etc				7.0%						1.2%
				76,980						2,621
Training	5.1%	1.6%	11.4%	11.0%	3.6%	3.3%	3.5%	7.4%	8.4%	4.3%
	279,999	35,103	277,684	120,969	146,675	11,551	94,788	502,026	62,956	9,712
Travel / per diem	29.4%	29.7%	25.7%		20.8%		20.8%	23.6%	31.6%	
	1,601,074	647,388	623,581		856,210		568,303	1,589,774	237,534	
Planning & management—meetings, M&E, etc	15.0%	15.2%	17.3%	19.0%	11.6%	1.1%	11.0%	15.8%	21.6%	1.1%
	815,584	331,505	419,769	208,946	478,865	3,989	301,124	1,066,414	161,856	2,489
Equipment and materials used dispensing SMC						12.9%				9.5%
						45,657				21,391
Information, education, social mobilization	2.7%	5.3%	8.5%	5.0%	5.7%	1.6%	2.6%	2.6%	16.4%	1.2%
	147,905	115,952	207,505	54,986	236,109	5,554	69,965	173,373	122,978	2,651
Other	1.3%	1.4%	6.6%	2.0%	1.2%		3.3%	2.4%	1.5%	
	68,689	30,749	160,580	21,994	51,558		89,521	160,952	10,955	
Total in USD	5,437,001	2,181,415	2,430,302	1,099,715	4,126,189	353,053	2,736,679	6,742,178	750,947	224,875

[1] Intervention or provider costs include recurrent costs (e.g., personnel costs, supplies, operating/maintenance, training, communications, etc.) and capital (or fixed) costs include for example, vehicles, buildings/infrastructure, equipment, transport, etc.

[2] See Table 1 Characteristics of studies included for the seasonal malaria chemoprevention (SMC) costing review for more details

[3] Adding a fourth monthly SMC round would be expected to increase total costs by ~28–30% (19). We omitted the cost of research participation incentives reported by the study as these pertain to the study, not the SMC intervention

[4] The study reported percentages for the categories instead of costs, the authors calculated the cost by applying the percentages to the total reported cost. We grouped the costs of the "dosing exercise" and "supervision", this includes transport and travel costs as the study did not report these estimates separately

[5] Includes NGO program management and program management salaries

[6] Study does not specify which costs are grouped under "other"

Table 4 Economic cost for SMC delivery by percentage of total cost, cost per ingredient (converted to US 2023)

Intervention or provider costs[1] (%) and USD	Burkina Faso (3)	Chad (3)	Gambia (Rep of The) (3)	Ghana (18)[2]	Guinea (3)	Mali (16)	Mali (3)	Niger (3)	Nigeria (3)	Senegal (19)
Target population	*1,462,033*	*573,766*	*90,925*	*148,104*	*426,278*	*104,255*	*1,461,520*	*1,210,863*	*6,960,987*	*180,000*
Number of monthly SMC cycles administered	*4*	*4*	*4*	*4*	*4*	*4*	*4*	*4*	*4*	*3*
SMC drugs and supplies, incl drug transport	37.7%	34.7%	25.9%		42.6%	32.7%	51.9%	31.6%	19.3%	18.4%
	2,272,387	922,185	668,350		1,819,290	95,282	1,523,877	2,398,526	148,679	41,301
Drug administration—salaries, supervision, etc	4.2%	3.7%	2.8%	80.9%	12.6%	49.4%	3.0%	11.2%	0.8%	65.1%
	251,363	98,533	72,833	1,718,536	537,484	143,528	89,101	851,112	5,989	145,454
Pharmaco-vigilance, drugs for side-effects, etc										1.2%
										2,621
Training	4.6%	1.3%	10.8%	5.7%	3.4%	4.8%	3.2%	6.6%	8.2%	6.0%
	279,999	35,103	277,684	120,969	146,675	14,007	94,788	502,026	62,956	13,438
Travel / per diem	26.5%	24.4%	24.2%		20.1%		19.4%	20.9%	30.8%	
	1,601,074	647,388	623,581		856,210		568,303	1,589,774	237,534	
Volunteer opportunity costs[2]	9.9%	17.9%	5.7%		3.3%		6.7%	11.2%	2.6%	
	594,531	476,256	148,223		142,569		197,188	847,080	19,736	
Planning & management—meetings, M&E, etc	13.5%	12.5%	16.3%	9.8%	11.2%	1.7%	10.3%	14.1%	21.0%	1.8%
	815,584	331,505	419,769	208,946	478,865	4,998	301,124	1,066,414	161,856	4,053
Equipment and materials used dispensing SMC						9.4%				6.1%
						27,436				13,525
Information, education, social mobilization	2.5%	4.4%	8.0%	2.6%	5.5%	1.9%	2.4%	2.3%	16.0%	
	147,905	115,952	207,505	54,986	236,109	5,554	69,965	173,373	122,978	
Other	1.1%	1.2%	6.2%	1.0%	1.2%		3.1%	2.1%	1.4%	1.4%
	68,689	30,749	160,580	21,994	51,558		89,521	160,952	10,955	3,117
Total in USD	**6,031,532**	**2,657,672**	**2,578,525**	**2,125,431**	**4,268,758**	**290,805**	**2,933,866**	**7,589,258**	**770,683**	**223,509**

[1] Intervention or provider costs include recurrent costs (e.g., personnel costs, supplies, operating/maintenance, training, communications, etc.) and capital (or fixed) costs include for example, vehicles, buildings/infrastructure, equipment, transport, etc.

[2] The study calculated economic costs from both the provider and societal perspective, the provider costs are included in the table, the societal cost was estimated to be 2.3 times higher

Table 5 Mapping of the cost ingredients reported by each study

	Pitt et. al	Diawara et. al	Nonvignon et. al	Gilmartin et. al	Faye et. al
SMC drugs and supplies—incl. drug transport, etc	X	X	X	X	X
Drug administration—incl. salaries, supervision, etc	X	X	X		X
Pharmacovigilance			X		
Training	X	X	X	X	X
Travel / per diem				X	
Volunteer stipend				X	
Planning & management—meetings, M&E, etc	X	X	X	X	X
Equipment and materials used in dispensing SMC	X	X			X
Information, education, and social mobilization	X	X	X	X	
Other	X			X	X

calculations, leading to differences in activities included in aggregate cost estimates for SMC delivery. Certain ingredients costed by the studies may be hidden, as they may have been grouped into broader categories. Some studies did not report all the examples listed in Table 5; for example, if a study did include cost estimates for SMC drugs but not for drug transport, the study still received a check mark.

Although pharmacovigilance reporting is considered a key element of SMC, only one study explicitly detailed its costs. One study assessed SMC cost data as part of a scale up package including bed nets, intermittent preventive treatment in pregnancy, rapid diagnostic tests, and artemisinin combination therapy, presenting the unit cost per capita for different combinations of packages [17]. In Burkina Faso, Mali, and Niger, SMC was reportedly integrated with the provision of rapid diagnostic tests for malaria, malaria treatment, malnutrition screening, and referrals, but no costing data was reported regarding these other services [3].

Cost and cost-effectiveness of SMC delivery

SMC cost per child and cost-effectiveness values are shown in Tables 6 and 7, with the reported unit costs varying by study. Five of the six studies reported both financial and economic cost estimates. In terms of financial costs, the cost per round per child ranged from $0.70 to $4.19 (n = 4), while annual cost per child ranged from $1.71 for three cycles in Senegal and ranged from $3.18 to $12.46 for countries with four cycles of SMC (n = 5). Economic costs were higher, with cost per round per child ranging from $0.83 to $2.09 (n = 3) and annual cost per child ranging from $2.11 to $29.06 (n = 4). ICERs, summary measures of the economic value of an intervention generated by dividing incremental cost by incremental effect of an intervention with a comparator,

Table 6 Cost per child estimates for SMC delivery

SMC[1] cost per child in USD 2023*					
Country, reporting year	**Cycles of SMC**	**Cost per cycle per child (financial)**	**Cost per cycle per child (economic)**	**Annual cost per child (financial)**	**Annual cost per child (economic)**
Burkina Faso, 2016 (3)	4 cycles	–	–	4.29	4.80
Chad, 2016 (3)	4 cycles	–	–	3.96	4.90
Ghana, 2015 (18)	4 cycles	4.19	–	12.46	29.06
Guinea, 2016 (3)	4 cycles			4.29	4.52
Mali, 2014 (16)	4 cycles	0.93	1.09	3.71	4.36
Mali, 2016 (3)	4 cycles	–	–	4.01	4.17
Niger, 2016 (3)	4 cycles	–	–	3.18	3.44
Nigeria, 2016 (3)	4 cycles	–	–	4.51	5.09
The Gambia, 2016 (3)	4 cycles	–	–	10.15	10.41
Senegal, 2010 (15)	3 cycles	0.70	0.83	–	–
Senegal, 2010 (19)	3 cycles	1.69	2.09	1.71	2.11
Senegal, 2014 (17)	-	–	–	3.07	–

* All estimates converted to USD 2023

Table 7 Cost effectiveness of SMC delivery

Study	Metric	Cost in USD 2023*	Range	Comments
Senegal, 2014 (17)	Cost per disability-adjusted life years (DALY) averted for Scale Up for Impact (SUFI) * + SMC	98.0	78.7–145.8	*Part of a package with SUFI, incl bed nets, intermittent preventive treatment in pregnancy, rapid diagnostic tests, and artemisinin combination therapy
Mali, 2014 (16)	Financial cost per childhood episode averted	4.8	3.2–8.1	3% discount, actual coverage (75.3%)
	Economic cost per childhood episode averted	5.4	3.6–9.1	
	Economic cost per DALY averted	182.9	171.5–194.3	
	Economic cost per Death averted	18,418.8	17,277.1–19,560.5	
Ghana, 2015 (18)	Economic cost per additional child death averted (provider)	4,254.9	3,964.5–4,828.0	3% discounting, 80% effectiveness
	Economic cost per additional child death averted (societal)	12,716.8	11,296.7–14,561.6	
	Economic cost per additional case averted (provider)	138.1	128.7–156.7	
	Economic cost per additional case averted (societal)	412.7	366.7–472.6	
Burkina Faso, Chad, The Gambia, Guinea, Mali, Niger, Nigeria, 2016 (3)	Cost per malaria case averted		3.7–39.0	3% discounting, 80% effectiveness
	Cost per DALY averted		23.7–100.2	
	Cost per death averted		678.2–2866.4	

* All estimates converted to USD 2023

varied between studies. The ICER per clinical case averted ranged from $5.41 to $138.03 (n = 3), ICER per DALY averted ranged from $24.51 to $182.88 (n = 3), and ICER per death averted from $688.86 to $18,418.81 (n = 3).

In terms of the integrating SMC with other interventions, one study looked at the cost of DALYs averted when SMC was delivered as part of a package with scale-up for impact (SUFI), including bed nets, intermittent preventive treatment in pregnancy, rapid diagnostic tests, and artemisinin combination therapy [17]. In Burkina Faso, Mali, and Niger, SMC was reportedly integrated with the provision of rapid diagnostic tests for malaria, malaria treatment, malnutrition screening, and referrals [3]; however, data was unavailable on the cost per outcome of these interventions.

Quality of selected studies

Studies that examined only costs and cost offsets and those including economic evaluations were assessed per the CHEERS scope [14]. Each of the six articles successfully met many of the CHEERS checklist evaluation items. With minor exceptions, checklist items pertaining to Methods, including 'Study population' (#5), 'Perspective' (#8), 'Time horizon' (#9), 'Selection', 'Measurement', and 'Valuation of outcomes' (#11–13), and 'Currency, price date, and conversion' (#15) were consistently reported across all selected studies. Minor discrepancies included the lack of reporting 'Discount rate' (#10) in one study [19] and 'Study population' (#5) in another [17]. Three studies [17–19] lacked reporting on 'Characterizing distributional effects' (#19) compared to two studies [15, 16] who included it. One study [19] did not report 'Characterizing uncertainty' (#20). None of the selected studies included a health economic analysis plan (#4). Results topics were also reported consistently across studies, except for 'Effect of engagement with patients and others affected by the study' (#25), which was not reported by any of the studies whereas the approach of engagement was reported by two studies [3, 17]. These discrepancies contribute to the difficulty in comparing SMC costs across studies.

Discussion

This systematic review assessed the evidence on the cost and cost-effectiveness of SMC delivery, and to our knowledge, is the first systematic review documenting and comparing detailed cost data of delivering SMC. The review provides insights on the resource needs and cost drivers of SMC programs to date, cost benchmarks to inform future SMC planning and resource allocation, as well as recommendations for the standardization of SMC costing methods to facilitate cost comparisons and decision-making. This is especially relevant given fiscal constraints among countries with high malaria burdens, the emergence of new malaria prevention technologies such

as vaccines and monoclonal antibodies [22], and stagnating reductions in malaria morbidity and mortality [23] which have been aggravated by insecticide and antimalarial drug resistance, difficulty eliminating vector populations [24], and the rise of invasive urban vectors [25].

Despite the widespread implementation of SMC in 17 countries to date, only six studies with primary cost data on the delivery of SMC were identified published between 2016 and 2021, spanning nine countries. Of these studies, five captured cost data of SMC pilots (i.e., first-time campaigns) while the Gilmartin et al. study is the only one that assessed the cost of large scale and established SMC campaigns. This suggests that routine cost data from mature SMC programs remains largely unpublished since WHO's recommendation for SMC implementation in 2012, contributing to a thin evidence base.

The review found a wide variation in the cost per child covered with SMC, largely stemming from differences in scale (i.e., target populations of campaigns), variation in cost ingredients reported, variation in categorization of these ingredients, and the perspective of the analysis. The total annual financial cost per child covered with SMC ranged from $1.71 to $12.46 and the total economic cost ranged from $2.11 to $29.06, with drug administration costs representing the largest cost driver followed by SMC drugs and supplies and training. These estimates are slightly higher than those reported by Togo et al. in 2023, which estimated the median cost for full SMC treatment at $4.32 [26]. This review also found that among the three studies reporting ICERs, SMC is considered highly cost-effective intervention with the ICER per DALY averted ranging from $24.51 to $182.88 in seven countries, which is well below the Gross Domestic Product per capita of each of the countries included in the studies (Burkina Faso 874.1, Chad 719.4, Ghana 2,238.2, The Gambia 843.8, Guinea 1663.9, Mali 897.4, Niger 618.3, Nigeria 1621.1, Senegal 1746.0 in 2023) [27]. These findings are consistent with those by Togo et al. [26] which reviewed 17 peer-reviewed cost effectiveness studies without assessing the primary data informing the analyses.

The perspectives of SMC cost analyses were largely from the provider perspective with only one study capturing caregiver productivity losses. Yet, the limited evidence suggests that households participating in SMC campaigns experience considerable opportunity costs in terms of lost wages and time spent. The study by Nonvignon et al. found that indirect costs accounted for about 74% of the total societal costs and 24% of the total provider costs. This conflicts with a common assumption that household opportunity costs for SMC are low given door-to-door administration [28]. Studies that fail to take societal costs into account may underestimate the cost of the intervention, resulting in a downward bias of the cost effectiveness estimates, though only a dramatic shift would truly impact the cost effectiveness of SMC. Moreover, one study accounted for costs funded by both government and non-governmental organizations (NGOs), which played a considerable role in the scale-up of SMC through the Unitaid-funded ACCESS-SMC project. NGOs continue to play a significant role in SMC delivery in many countries, adding uncertainty on future operations because of their over dependence on donor financing.

While studies adhered to most elements in the CHEERS checklist, they varied considerably in terms of the level of detailed cost ingredients and activities necessary for SMC implementation. This further emphasizes the need for standardized reporting of explicitly defined SMC cost ingredients and activities needed for implementation. For example, Gilmartin et al. [3] explicitly reported per diems for volunteer SMC distributors in the total cost of SMC delivery. However, other studies may have grouped these costs with other line items, such as delivering to distribution points in Diawara et al. [16]. Likewise, delivery methods were not clearly captured while drug transport and supply chain costs differ between a door-to-door approach and fixed site delivery of SMC. Standardization of costing methodologies, accounting for potential differences in delivery methods, could therefore help to ensure comparability and enable specific tailoring of malaria control packages at the global, national, and regional levels. Clearly defining and outlining the study perspective and the impact of mortality and discount rates on ICERs are best practices and should also be considered as best practices for future studies. These nuances can impact the calculated total cost of delivery and should be outlined in a manner that allows for comparison between studies, country contexts, and delivery methods.

The review highlights the need for clearly defining ingredients to ensure clarity on consistency within studies and opportunities for efficiency and cost reductions within SMC delivery. SMC costing definitions must also account for different costs per cycle when calculating the annual cost per child. For example, cost estimates for training may reduce over time, as training needs might decrease in frequency or duration after SMC distributors gain experience throughout the following cycles. Further research should explore how to apply existing methodologies to standardize costing SMC such as those developed by the Immunization Costing Action Network [29]) to SMC-specific costing efforts. This is especially important when comparing different prevention methods, as it gets even more complicated to compare different

preventive interventions given the differences in efficacy and the target populations.

The significant reduction of malaria in children under five years due to SMC, as demonstrated in many recent studies, supports the need to sustain and broaden the implementation of SMC [30] as part of a comprehensive prevention strategy while more evidence on new technologies is generated. While SMC remains a largely vertical intervention, there may be opportunities for future cost-sharing and service integration. Future research should consider opportunities for sharing costs with other community-based interventions and leveraging existing supply chain, transportation, training, and other overhead costs of SMC. Recent evidence demonstrates the enhanced effectiveness of SMC when combined with the Expanded Programme of Immunization, and the new RTS, S/AS01 (Mosquirix) [31]. The integration of SMC with other community-based health interventions (e.g., deworming and vitamin A campaigns, integrated community case management programmes, IEC) present opportunities for leveraging SMC campaigns for greater health impact [19].

Limitations

One of the limitations of this review is the low number of published studies with primary data identified since 2012. Both SMC delivery methods and study heterogeneity further complicate our ability to compare across these studies. To accurately assess the cost and cost-effectiveness of SMC there is a need for standardized costing methods and reporting including clearly defined ingredients and technical approaches as well as units of measurement. Standardization is also important to be able to compare SMC investments with other malaria prevention methods, and to answer questions around the possibility of integration into existing routine community health service delivery.

Conclusions

This is the first systematic review documenting evidence of the cost of delivering SMC. Studies did not cost mature programmes, but pilots or relatively new campaigns. The overall lack of research identified from 2012 onward suggests the need for more up-to-date and routine SMC costing data to augment the current evidence base and enhance the understanding of the resource needs of mature SMC programmes to inform planning and resource allocation for malaria prevention. Among the six studies identified, there was a wide variation in the financial and economic cost per child covered with SMC given differences in the scale of SMC campaigns, the cost ingredients and categories reported, and the perspective of the analysis. Standardizing an approach to SMC costing would facilitate comparability across studies and better inform resource needs. Moreover, capturing the societal costs of SMC, particularly the opportunity costs experienced by households, would allow for a better understanding of the full costs of SMC delivery.

Supplementary Information

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Supplementary material 1
Supplementary material 2
Supplementary material 3
Supplementary material 4
Supplementary material 5
Supplementary material 6
Supplementary material 7

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Author contributions
AR, CG, JN conceptualized the study. AR and MH conducted the initial database search. IM, MH, and SH screened and selected articles. AR resolved discrepancies. AR, IM, MH, and SH extracted data from select articles and were major contributors in writing the manuscript. CG, DW, RO, and JN revised and edited the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials
The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

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