Systematic Review

Use of mathematical modelling to estimate the impact of interventions and risk factors on cardiovascular diseases in Africa: A scoping review

Wingston Felix Ng'ambi[1,2]*, Janne Estill[1], Adamson Sinjani Muula[3,4,5], Olivia Keiser[1]

1. Institute of Global Health, University of Geneva, Geneva, Switzerland
2. Health Economics and Policy Unit, Department of Health Systems and Policy, Kamuzu University of Health Sciences, Lilongwe, Malawi
3. Africa Centre of Excellence in Public Health and Herbal Medicine (ACEPHEM), Kamuzu University of Health Sciences, Blantyre, Malawi
4. Department of Public Health and Family Medicine, Kamuzu University of Health Sciences, Blantyre, Malawi
5. Professor and Head, Department of Community and Environmental Health, School of Global and Public Health, Kamuzu University of Health Sciences, Blantyre, Malawi

***Corresponding Author: Wingston Felix Ng'ambi**; E-mail: wingston.ngambi@gmail.com

Abstract

Background

Achieving health-related Sustainable Development Goals (SDGs) in Africa is increasingly threatened by the rising burden of cardiovascular diseases (CVD), exacerbated by limited healthcare infrastructure and constrained resources. Mathematical modelling offers a powerful tool for informing CVD prevention and control strategies; however, its application in Africa remains poorly understood. This scoping review aims to map existing modelling studies, identify methodological and contextual gaps in the literature, and inform future model development for effective decision-making.

Methods

This scoping review followed Levac et al.'s framework and PRISMA-ScR guidelines to explore how mathematical models have been used to study CVD in Africa. We included studies published since 2000 that used structured models to simulate how CVD progresses and responds to risk factors or interventions. Our search, conducted in PubMed and Google Scholar, focused on models relevant to local settings and policy. Data were extracted and analysed thematically. As the review used only publicly available data, no ethical approval was needed. The protocol was registered with the Open Science Foundation.

Results

CVD modelling studies in Africa span nearly two decades, with a geographic concentration in South Africa, Nigeria, and Kenya, while many low-resource and fragile settings remain underrepresented. A range of modelling approaches were used, including decision-analytic models, microsimulation, and WHO-CHOICE frameworks, with recent studies increasingly incorporating dynamic and stochastic elements. Interventions modelled included pharmacological treatments (e.g., statins, antihypertensives), lifestyle modifications (e.g., salt reduction, increased physical activity), and community-level prevention strategies. Many models assessed combinations of interventions and accounted for multiple risk factors. However, limitations in local data availability led to reliance on extrapolated estimates, assumptions about treatment effects, and expert-informed parameterization. Few studies calibrated models to local epidemiological data or disaggregated outcomes by equity dimensions such as gender, income, or geography.

Conclusion

While CVD modelling in Africa has progressed, its utility for informing real-world policy remains limited by insufficient incorporation of health system constraints and equity considerations. To maximize impact, future efforts should prioritize the development of context-specific microsimulation frameworks that integrate system dynamics, reflect local implementation realities, and use country-specific data for calibration.

KEYWORDS: Mathematical modelling, cardiovascular diseases, cost-effectiveness, CVD, Africa, scoping review

Introduction

About one-third of all deaths globally are caused by cardiovascular diseases (CVD)[1], which are the leading cause of morbidity and mortality worldwide[1]. In 1990, there were slightly over 12 million deaths worldwide from cardiovascular causes; by 2019, this number had increased by more than one-third to 18.6 million[1,2]. Furthermore, between 1990 and 2019, CVD rose from the sixth to the second most common cause of mortality in sub-Saharan Africa (SSA), surpassing other intestinal diseases, HIV/AIDS, and malaria[3]. In SSA, CVD accounted for 22.9 million Disability-Adjusted Life Years (DALYs) and 38.3% of non-communicable disease (NCD) fatalities, making them the leading cause of the continent's overall NCD burden[4]. Over the past 20 years, increasing urbanisation, shifting lifestyles, and greater exposure to behavioural and metabolic risk factors such as diabetes, hypertension, smoking, and physical inactivity have contributed to the increasing burden of CVD in Africa[5,6]. One of the major obstacles to the attainment of the Sustainable Development Goals (SDGs) pertaining to health in Africa is this escalation of CVD which is made worse by fragile healthcare systems and scarce resources[7]. Mathematical modelling can help address this complex and multidimensional problem[8].

https://dx.doi.org/10.4314/mmj.v38i1.6

Mathematical models provide a framework linking exposures, interventions, and disease outcomes, thereby informing policymakers on the effectiveness of interventions[9–11]. Mathematical models range in complexity from simple spreadsheet calculations to complex system dynamics and agent-based models[11]. Furthermore, such models allow researchers and policymakers to anticipate future illness patterns, evaluate the impact of treatments, and optimise resource allocation by combining epidemiological, demographic, and intervention data[12]. Such evidence is crucial in Africa, where health systems have to balance conflicting goals with constrained funding, and where direct empirical research is sometimes hampered by data gaps[13]. Although mathematical models have enormous potential to guide successful prevention and control efforts for CVD, their use in Africa is still suboptimal[14].

The synthesis of evidence from mathematical models is frequently complicated by the many approaches, assumptions, and data sources used in these studies, leaving important gaps in our knowledge of how different therapies and risk factors affect CVD outcomes. In order to map the existing state of mathematical modelling studies, identify knowledge gaps, and find ways to improve modelling methodologies for CVD in Africa, a thorough scoping review is necessary. We aimed to address the following questions to aid understanding of the extent of current modelling studies: (a) What are the most common types of models used to estimate the impact of CVD interventions and risk factors in Africa?; (b) What CVD outcomes are modelled (e.g., mortality, morbidity)?; (c) Which interventions (e.g., aspirin, statins, lifestyle changes) and risk factors (e.g., hypertension, physical inactivity) are considered?; (d) How well do these models account for the unique epidemiological, sociocultural, and health system contexts of Africa?; (e) What data gaps and methodological limitations hinder the accuracy and applicability of these models?; and (f) what are the opportunities to improve modelling approaches for effective CVD prevention and control in Africa?

Methods

Levac et al.'s framework[15] was selected to guide the review, as it offered clear and comprehensive direction, expanding on the original six-stage approach to scoping reviews first introduced by Arksey and O'Malley[16]. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Scoping Reviews (PRISMA-ScR) statement was followed in conducting this review[17]. The checklist for this review is provided in S1 File.

Inclusion and exclusion criteria

This scoping review included mathematical models that use formal equations to simulate the progression of CVD over time, incorporating the effects of risk factors, interventions, and/or health system dynamics[18]. This review included mechanistic models that explicitly simulate causal pathways of NCD risk factors on CVD outcomes. Only papers published in English after 2000 were considered to reflect recent developments in mathematical modelling of CVD. Studies reporting any health-related measures either as primary or secondary outcome (including direct measures of CVD illness (e.g. death) or outcomes based on other health measures (such as the Incremental Cost-Effectiveness Ratio) were included[19]. Studies were eligible if they targeted any country of Africa according to the United Nations Statistics Division's regional classifications[19,20].

The exclusion criteria are intended to keep the scoping review's goals in focus and pertinent. Studies that predominantly address non-CVD outcomes were excluded. We also excluded phenomenological models that primarily rely on statistical curve-fitting without representing underlying biological or epidemiological mechanisms. Furthermore, editorials, comments, and opinion pieces that do not provide primary data or modelling results were not taken into account.

Literature search

PubMed was selected because it is a major biomedical database with strong indexing of public health, epidemiology, and health services research. Google Scholar was included to improve the retrieval of multidisciplinary and less well-indexed studies, including regionally disseminated work and grey literature relevant to African settings. Together, these databases provide complementary coverage: PubMed offers structured biomedical indexing, while Google Scholar allows broader capture of multidisciplinary and regionally relevant literature. Given the applied and policy-oriented nature of mathematical modelling studies, this combination was considered appropriate for identifying both peer-reviewed and difficult-to-locate records.

Given the applied and policy-oriented nature of mathematical modelling studies, we considered this combination appropriate for identifying both peer-reviewed and difficult-to-locate records. This approach was essential to ensure that potentially relevant models, especially those developed in or adapted for Africa, were not overlooked due to indexing limitations. These open-access resources are widely used and provide access to a vast amount of high-quality, peer-reviewed research across various disciplines, including health and medical studies. A combination of keywords and subject headings (such as MeSH terms) was used, organized into three key areas: (a) Disease focus, including cardiovascular diseases and related terms, (b) Methods, such as mathematical modelling, simulation, and cost-effectiveness, and (c) Geographical focus, specifically Sub-Saharan Africa. To improve reproducibility, the full electronic search strategy for PubMed is provided in Box 1.

Study screening and selection

A step-by-step approach was used to find studies that were relevant for inclusion. On 2nd March 2025, a search was conducted across two electronic databases, PubMed and Google Scholar. After identifying the relevant studies, the bibliographies of the selected articles were manually reviewed to find any additional sources of information that might be useful. To guarantee the inclusion of pertinent studies, study screening and selection were carried out in two stages[21]. In order to find potentially relevant research based on predetermined inclusion and exclusion criteria, titles and abstracts were first evaluated[22]. The full-text publications of chosen studies were then examined to verify eligibility. Although current guidelines recommend that both the review process and the extraction and analysis of data be carried out by a multidisciplinary team to enhance the validity of findings 15,19, this review was undertaken as part of the lead author's Ph.D. research. As such, it was conducted independently, without the involvement of additional authors.

Data extraction

To ensure consistency and capture all relevant details, a

structured form was developed and used to guide data extraction across studies. Key information collected included study details such as the author, year, country, and design; the type of mathematical models applied (e.g., Markov models); and sources of data like population surveys and health registries (S2 File). Health-related outcomes such as CVD morbidity and mortality, the incidence and prevalence of conditions like hypertension, coronary artery disease, and stroke as well as measures derived from these like QALYs and DALYs were recorded. Economic outcomes, including healthcare costs and cost-effectiveness metrics (like Incremental Cost-Effectiveness Ratios (ICERs)), were also extracted. Information on model performance (e.g., accuracy, sensitivity, specificity) and the impact of interventions (such as expanded healthcare access or reduced risk factor prevalence) was also documented. This comprehensive approach allowed for a clear understanding of how mathematical models have been used to evaluate interventions and risk factors for CVD in Africa. Model validation refers to evaluating whether a model accurately represents real-world outcomes. This includes calibration to observed epidemiological data, comparison with national or regional statistics, use of established risk prediction tools, and sensitivity analyses. Information on validation approaches was extracted where reported.

Data analysis

The results from the included studies were mapped and summarised descriptively[23], including the types of mathematical models used, the outcomes evaluated (e.g., cost-effectiveness, morbidity and death from CVD), and the interventions or risk factors taken into consideration[24]. To find common patterns and gaps in the literature, a qualitative synthesis was conducted[25]. To provide a thorough picture of the state of modelling studies on CVD in SSA, studies were classified according to modelling techniques/attributes used (i.e., microsimulation, cost-effectiveness analysis or Markov models), outcome measures, and study features. A thematic analysis was also used to investigate how various modelling approaches handle certain research problems and policy implications[26]. Additionally, data from the identified studies were examined for consistency and heterogeneity, especially with regard to the assumptions made, the data sources consulted, and the techniques used for model validation[27].

Ethical consideration

This scoping review relied solely on publicly accessible literature and did not involve human participants, identifiable personal data, or direct patient contact; therefore, ethical approval was not required. This is consistent with the reporting approach recommended under the PRISMA-ScR framework for reviews based on publicly available sources[28]. The protocol was registered with the Open Science Foundation, https://doi.org/10.17605/OSF.IO/WF64H.

Results

Search results

Figure 1 shows the search and screening processes within this review. Out of 2,626 records initially identified from PubMed and Google Scholar, 2,574 remained after removing duplicates. After screening titles and abstracts, 120 full-text papers were assessed, and 40 were included in the final review[29–44,44–67]. All the papers included in this review are shown in Table 1. Of these, 16 studies had model validation, while 24 did not. In the reviewed studies, validation was done through various methods such as calibration to observed data, comparison with national or regional health statistics, use of established risk scores, and sensitivity analyses. While some models were extensively validated, many studies did not report any explicit validation, highlighting inconsistency in methodological transparency across the literature.

General study characteristics

The geographic coverage of CVD modelling remains uneven. The countries included in CVD modelling studies were Tunisia, Egypt, Senegal, Ghana, Nigeria, Cameroon, Ethiopia, Kenya, Uganda, the United Republic of Tanzania, Zambia, and South Africa. Most CVD modelling studies in Africa have predominantly focused on South Africa, with a significant concentration also observed in East African countries like Ethiopia and Kenya.

Other nations, including those in Central and Western Africa, are underrepresented despite high CVD incidence. Several studies also adopt a regional lens, such as Bertram et al. (2021)[68] and Kumar et al. (2022)[69], or intrapolate findings from global models (e.g., Ngalesoni et al., 2016[49]), reflecting the challenges of sparse local data. Although pragmatic, this approach limits local specificity and hinders implementation of context-sensitive interventions. Overall, while the number of modelling studies in SSA is expanding, studies remain scarce or are lacking in many critical settings; especially rural, fragile, or data-scarce areas.

The temporal distribution of modelling studies from 2000 to 2025 is shown in Figure 3. Most studies were published in 2016 and 2021, driven largely by studies focused on cost-effectiveness analyses, a practical approach to weigh the financial and health impacts of interventions like hypertension treatment or smoking cessation programs. While commonly used models that track individual-level outcomes over time or map disease progression through stages like "healthy" to "heart failure" have been consistently used since the mid-2010s, more complex approaches were used in the past decade. Recent studies increasingly incorporate stochastic methods (randomness to mimic real-world unpredictability, like varying treatment adherence rates) and integrating complex factors such as comorbidities or healthcare access gaps. This evolution mirrors a growing urgency to tackle CVD's rising toll in the region, where aging populations and lifestyle shifts are straining already fragile health systems. Overall, the field has shifted from basic projections to nuanced, data-driven tools that aim to turn research into actionable policies for a healthier future.

Modelling approaches and data sources

Diverse mathematical modelling methodologies were used. Most of the CVD modelling studies in Africa were Markov models (n=12, 30.0%), which simulate transitions between health states (e.g., hypertension → heart failure) to evaluate interventions like smoking cessation or treatment scaling. These are closely followed by decision-analytic models (n=10, 25.0%) and microsimulation models (n=9, 22.5%), both increasingly used to capture individual-level variability and long-term impacts of policies such as salt reduction or hypertension management. Models were grouped by their primary analytical focus rather than technical classification.

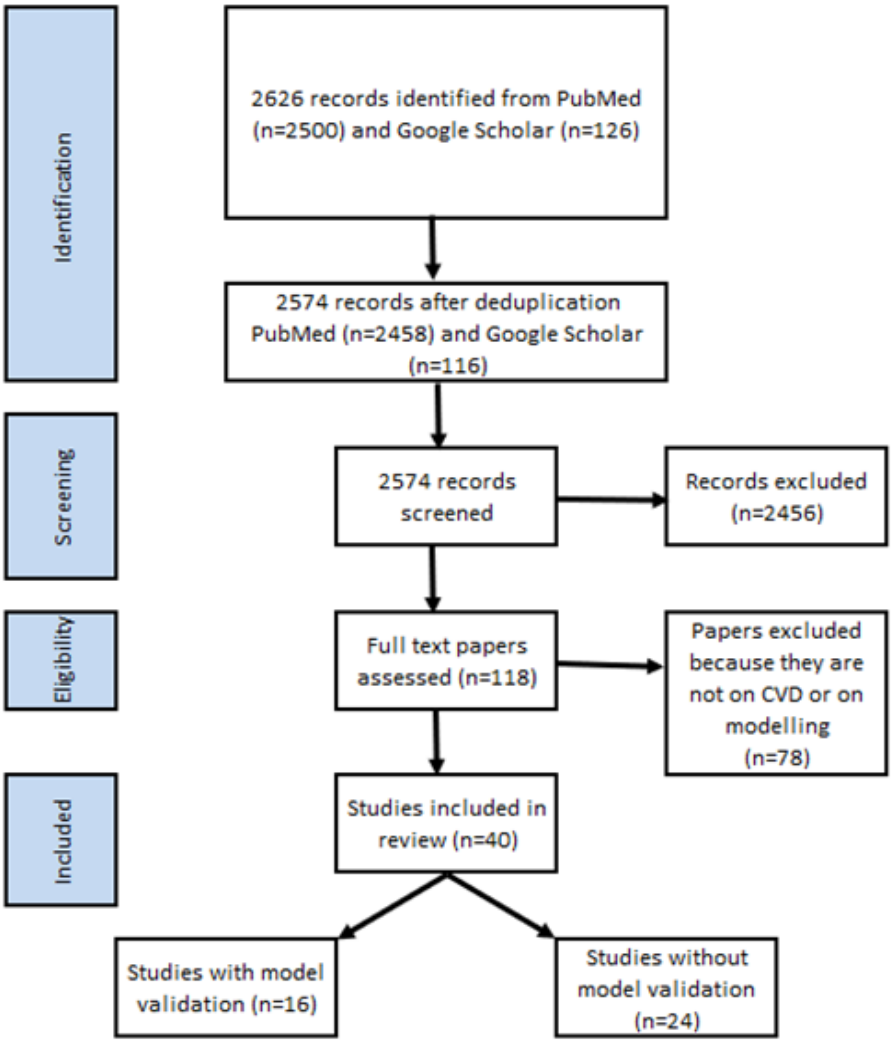

Fig 1: PRISMA diagram reporting search results for cardiovascular disease mathematical modelling in sub-Saharan Africa

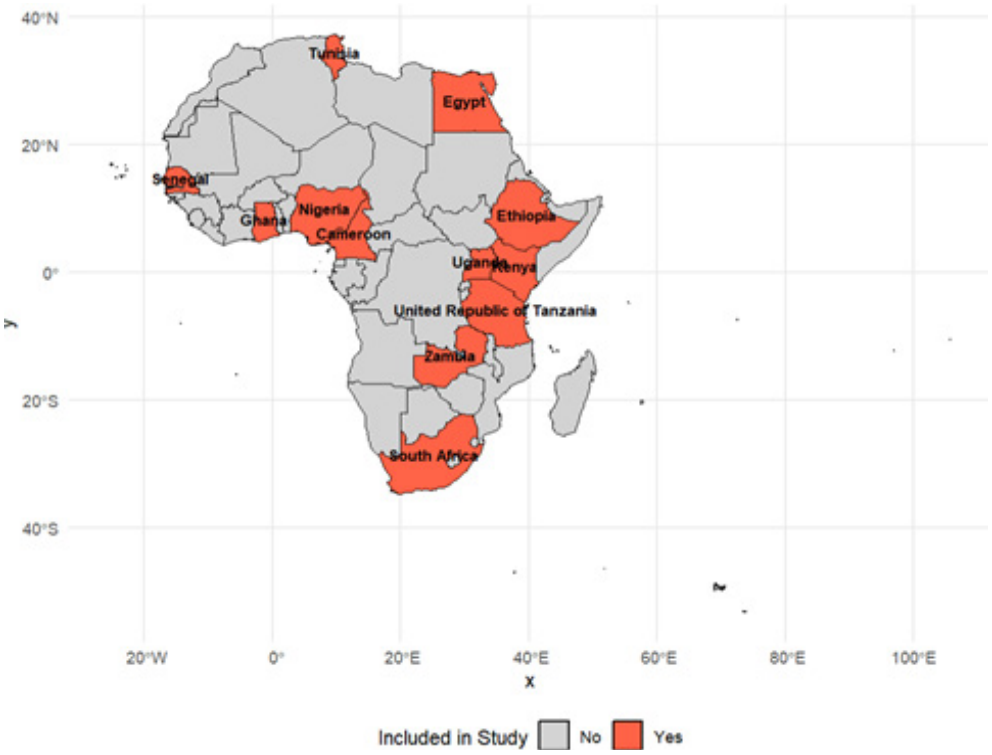

Figure 2: Geographic distribution of cardiovascular disease modelling studies in Africa (2005–2025), with colour intensity representing the number of included studies per country

https://dx.doi.org/10.4314/mmj.v38i1.6

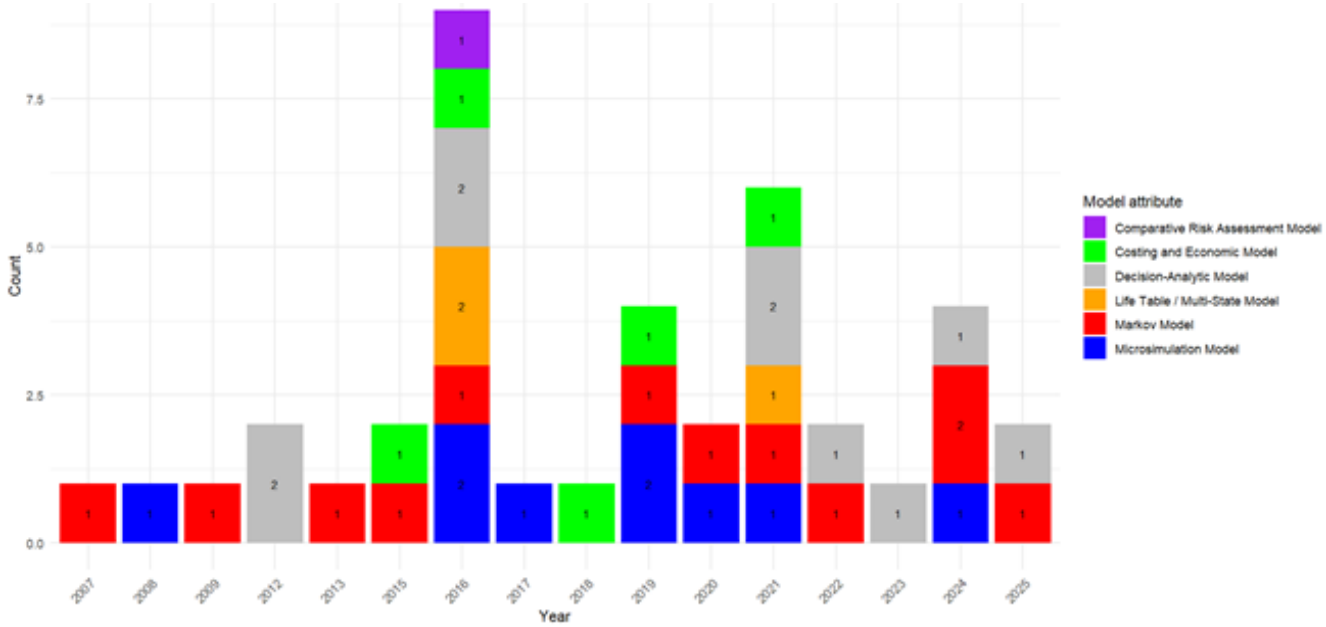

Figure 3: Cardiovascular disease mathematical model attributes by year in Africa

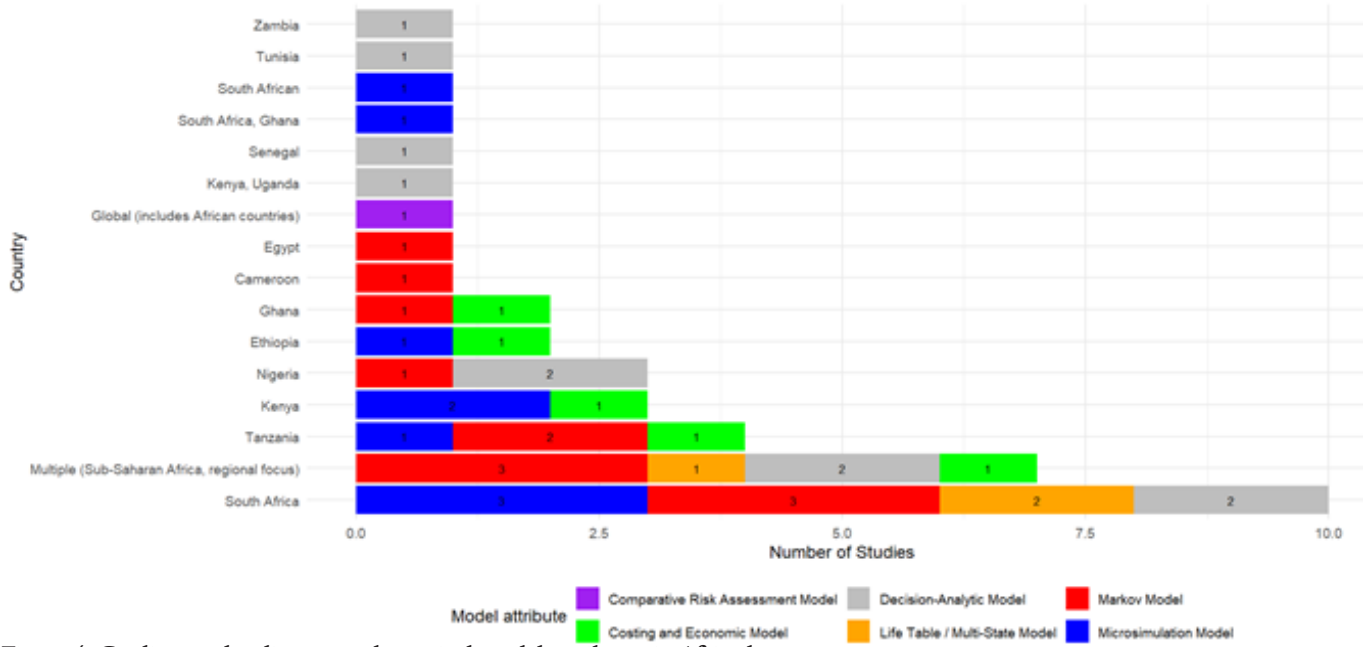

Figure 4: Cardiovascular disease mathematical model attributes in Africa by country

Economic models (n = 5, 12.5%) emphasised cost and affordability, while life table or multistate models (n = 3, 7.5%) captured disease progression, including some technically classified as Markov models. Rarely used approaches like comparative risk assessment models (n=1, 2.5%) highlight gaps in addressing population-wide risk factors (e.g., diabetes, obesity).

Figure 4 shows the distribution of CVD models by country and model type. South Africa stands out as a research hub for CVD modelling, hosting ten studies that employ a diverse toolkit of microsimulation, Markov models, life tables, and decision-analytic models to tackle issues like hypertension management and cost-effective interventions. Tanzania and regional studies covering multiple Sub-Saharan African countries also show strong activity, each contributing five or more studies using Markov models, economic evaluations, and policy-driven analyses. In contrast, nations like Zambia, Tunisia, Senegal, and bilateral collaborations (e.g., South Africa-Ghana) have only one study each. Global initiatives occasionally include African contexts, but localized efforts remain sparse outside the top-performing countries. This geographic disparity highlights gaps in leveraging data-driven tools to address CVD burdens across the region.

The modelling techniques applied are diverse, encompassing microsimulation (e.g., Basu et al., 201970; Subramanian et al., 2020[71]), cost-effectiveness analysis (e.g., Bertram et al., 2012[31]), decision-analytic models (Gaziano et al., 2015 36), Markov models (Lin et al., 2019[48]), and WHO-CHOICE cost-effectiveness frameworks (Bertram et al., 2021 68). More recent studies (e.g., D'Couto et al., 2024 42; Oamen et al., 2022[30]) are beginning to incorporate dynamic and stochastic elements, showing an evolution in methodological sophistication. For example, D'Couto et al. (2024) explored how smoking and HIV progression interact over time to affect the risk of cardiovascular diseases like lung cancer and stroke by building a model that tracked these changes statically and adapted changes in lifestyle and health. Also, Oamen et al., 2022 looked at how high blood pressure progresses in patients and how different treatments influence heart disease outcomes over time. They used a modelling approach that embraces the uncertainty of the real world; factoring in things like how well medications work from

https://dx.doi.org/10.4314/mmj.v38i1.6

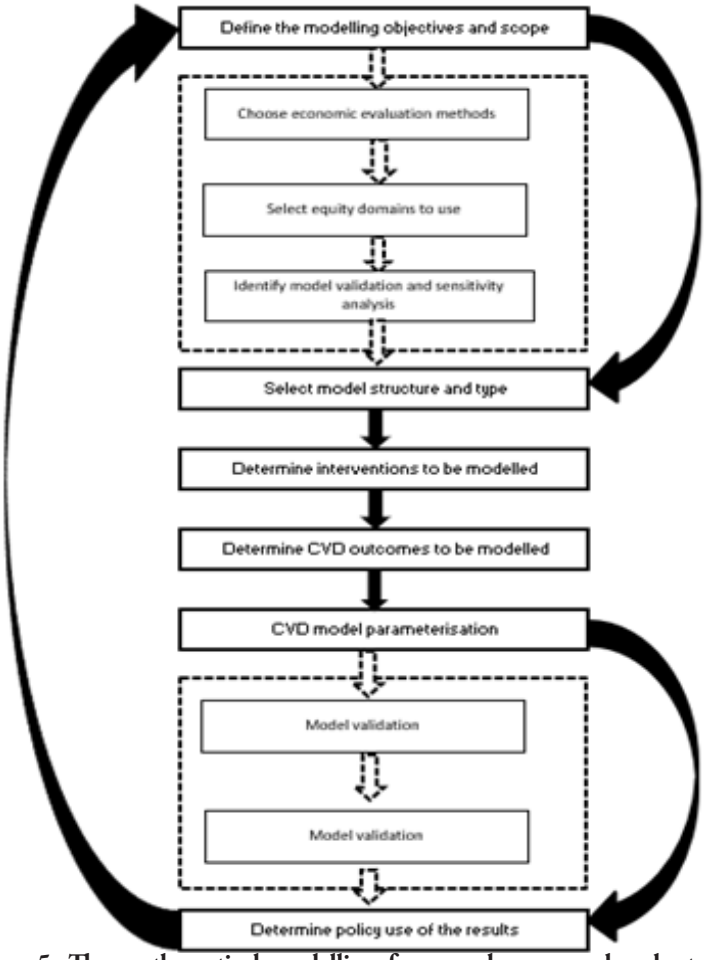

Figure 5: The mathematical modelling framework commonly adopted in studies on cardiovascular disease in sub-Saharan Africa

person to person and how costs can change; offering a more realistic picture of how cardiovascular disease develops and can be managed.

Primary data sources include Demographic and Health Surveys (n=6), national STEPwise reports (n=1), and empirical cohort data (n=2), though several studies relied on secondary estimates extrapolated from global databases (n=33) due to limited availability of country-level inputs. Most studies required adaptation of existing data to fit their modelling frameworks. This included extrapolation (e.g., Bertram et al. 2018[68]), standardization across population subgroups (e.g., Watkins et al., 2016[72]), or assumptions about treatment effects in heterogeneous populations (e.g., Bovet et al., 2006[35]). Strategies for handling missing data ranged from deterministic imputation to expert-informed parameterization. For example, Bertram et al. (2018) applied WHO-endorsed interpolation protocols for health expenditures and disease burden metrics[68].

The majority of these studies (75%) have centred around cost-effectiveness analyses of hypertension management strategies and population-level interventions such as salt reduction policies (e.g., Bertram et al., 2021[68]; Gaziano et al., 2015[36]; Cobiac et al., 2020[57]). In contrast, relatively few studies have explored the integration of CVD prevention with other non-communicable diseases or specifically examined gender-based differences in intervention effectiveness (e.g., Noubiap et al., 2019[73]; Mensah et al., 2025[63]). Modelled outcomes consistently included stroke (n=15), ischemic heart disease (n=2), and hypertensive heart disease (n=1), while some extended to diabetes (n=1), renal disease (n=1), and other NCD comorbidities (n=22, e.g., Bovet et al., 2006[35]; D'Couto et al., 2024[42]; Oamen et al., 2022[30]; Bertram et al., 2021[68]).

Interventions ranged from pharmacological treatments (e.g., statins, antihypertensives, aspirin) to lifestyle modifications and public health interventions like salt reduction campaigns. Combinatorial interventions, such as polypill strategies and integration of screening with treatment (e.g., Gaziano et al., 2015[36]; Watkins et al., 2016[72]), were frequently modelled for comparative purposes. Economic evaluation was a central component of nearly all studies, using cost-per-DALY or cost-per-QALY frameworks. Thresholds ranged from WHO's traditional 1–3 times Gross Domestic Product (GDP) per capita to country-specific willingness-to-pay thresholds. Bovet et al. (2006)[35] and Pichon-Riviere et al. (2023)[74] highlight the need for contextual threshold development that reflects fiscal space and public preferences. Cost components assessed include drug procurement, program delivery, outpatient visits, and productivity losses.

CVD modelling assumptions and validation

Common assumptions pertained to intervention efficacy, uptake, and price stability. Ethical considerations were often implicit but emerged in discussions on access equity, especially for the rural poor and women. Studies such as Watkins et al. (2016)[72] and Bertram et al. (2021)[68] explicitly addressed equity, proposing pro-poor targeting of CVD interventions. However, few models fully integrate equity metrics into cost-effectiveness frameworks.

Models varied in time horizon with some adopted short-term projections (1–5 years), often to assess feasibility or cost implications (e.g., Bovet et al. (2006)[35]; Oamen et al.,2022[30]), while others extended to long-term simulations (10–30 years) to capture chronic disease trajectories and intervention sustainability (e.g., Basu et al., 2018[70]; Kasaie et al., 2020[47];). Risk factors incorporated included hypertension, cholesterol, diabetes, smoking, alcohol use, obesity, and physical inactivity. More recent models have incorporated multidimensional risks, including social and behavioural determinants (e.g., D'Couto et al., 2024[42]; Oamen et al., 2022[30]). Analyses were split between evaluating individual interventions (e.g., salt reduction or statins alone) and examining synergies between multiple strategies. For instance, Gaziano et al. (2015) demonstrated how combined lifestyle and drug interventions outperformed isolated approaches in South Africa[36]. Watkins et al. (2016) used systems modelling to simulate cross-sectoral interventions and their indirect effects on CVD outcomes[72].

Validation practices were diverse. A few robust models calibrated their parameters using historical or real-world data (e.g., Basu et al., 2019[70]; Robberstad et al., 2007[39]; D'Couto et al.,2024[42]), while most relied on sensitivity analyses (either deterministic or probabilistic) to assess model robustness. Ekwunife et al., 2013[40] and Robberstad et al., 2007[39] used Monte Carlo simulations, while others used scenario analyses to test key assumptions and parameter bounds.

Modelling framework for CVD in African studies

Figure 5 outlines a systematic approach to CVD modelling in Africa, emphasizing key steps that guide the process from defining objectives to translating results into policy. The mathematical modelling framework commonly adopted in CVD studies in Africa follows a structured, iterative process.

https://dx.doi.org/10.4314/mmj.v38i1.6

Table 1: Characteristics of studies included in the scoping review for cardiovascular disease modelling in Africa: 2005-2025

Author(s)	Year of publication	Country or region	Model type	CVD outcomes modelled	Interventions Modelled	Methods for economic evaluation
Bertram et al. [35]	2021	Multiple (Sub-Saharan Africa, regional focus)	Costing and Economic Model	Mortality and morbidity reduction in cardiovascular disease (CVD)	Population-level policies (tobacco taxation, salt reduction, alcohol restrictions); Individual-level clinical interventions (hypertension treatment, statins, aspirin therapy)	Cost-effectiveness analysis using WHO-CHOICE framework
Bosu et al. [36]	2019	South African	Microsimulation Model	Cardiovascular disease or type 2 diabetes complications	WHO's package of essential non-communicable disease interventions (PEN) and South Africa's Primary Care 101 (SA PC 101) guidelines.	Cost-effectiveness analysis using DALYs averted and associated costs over the life-course
Bovet et al. [37]	2006	Kenya	Costing and Economic Model	Not explicitly modelled	Pharmacological treatment of hypertension and dyslipidaemia	Cost analysis from a patient perspective
Gaziano et al. [38]	2015	South Africa	Microsimulation Model	Stroke, ischemic heart disease	Paper-based risk assessment tool, Mobile application-based risk assessment tool	Incremental cost-effectiveness ratio (ICER), discounted costs and QALYs
Prozo-Martin et al. [39 40]	2021	Ghana	Costing and Economic Model	Hypertension control, cardiovascular events averted	Community-based Hypertension Improvement Project (ComHIP)	Incremental cost-effectiveness ratio (ICER), cost per DALY averted
Robberstad et al. [41]	2007	Tanzania	Costing and Economic Model	Cardiovascular disease events (e.g., myocardial infarction, stroke) averted	Single-pill polypill (aspirin, statin, and antihypertensive); individual drug components (aspirin, statin, antihypertensive alone).	Incremental cost-effectiveness ratio (ICER), cost per DALY averted
Ekwunife et al. [42]	2013	Tanzania	Markov Model	Stroke, Coronary Heart Disease	14 medical interventions including Acetylsalicylic acid, Hydrochlorothiazide, Atenolol, Nifedepine, Lovastatin and various combinations	Incremental cost-effectiveness ratio (ICER) and QALYs
Abdelhamid et al. [43]	2022	Nigeria	Markov Model	Cardiovascular events, mortality	Four classes of antihypertensive drugs (diuretics, calcium channel blockers, ACE inhibitors, beta-blockers)	Cost-utility analysis, cost-effectiveness acceptability curves and frontiers
D'Couto et al. [44]	2024	Egypt	Markov Model	Heart failure hospitalizations, cardiovascular mortality	Dapagliflozin vs placebo as add-on to standard of care, Dapagliflozin vs sacubitril/valsartan	Incremental cost-effectiveness ratio (ICER), cost per QALY averted
Dugas et al. [45]	2017	South Africa	Microsimulation Model	Stroke	Smoking cessation	Not applicable
Gaziano et al. [38 46]	2015	South Africa, Ghana	Microsimulation Model	CVD risk using Framingham risk equations	None	
Gaziano et al. [47]	2005	South Africa	Markov Model	Stroke, myocardial infarction, heart failure, chronic kidney disease	Hypertension treatment strategies (pharmacologic and non-pharmacologic)	Incremental cost-effectiveness ratio (ICER) analysis
Hickey et al. [48]	2024	Multiple (Sub-Saharan Africa, regional focus)	Markov Model	Myocardial infarction, stroke, heart failure, chronic kidney disease, cardiovascular mortality	Pharmacologic treatment of hypertension; Statin therapy for dyslipidemia; Combined interventions (hypertension + statins)	Incremental cost-effectiveness ratio (ICER) analysis
					Hypertension	

https://dx.doi.org/10.4314/mmj.v38i1.6

Table 1 Cont...

	2024	regional focus)	Markov Model	mortality	statins)	analysis
Kasaie et al. [49]	2020	Kenya	Simulation Model	Myocardial infarction, stroke, heart failure, cardiovascular mortality	Hypertension treatment, statin therapy, lifestyle interventions (e.g., salt reduction, smoking cessation)	
Lin et al. [50]	2019	South Africa	Markov Model	Myocardial infarction, stroke, cardiovascular mortality	Polypill (combination of aspirin, statin, and antihypertensive drugs) vs. usual care	Incremental cost-effectiveness ratio (ICER) analysis
Ngalesoni et al. [51]	2016	Tanzania	Markov Model	Cardiovascular disease events (combined), cardiovascular mortality	Pharmacologic treatment strategies for different CVD risk levels (with and without diabetes)	Incremental cost-effectiveness ratio (ICER) analysis, disability-adjusted life years (DALYs) averted
Oguta et al. [52]	2025	Multiple (Sub-Saharan Africa, regional focus)	Decision-Analytic Model	Myocardial infarction, stroke, cardiovascular mortality	Pharmacologic treatments (e.g., antihypertensives, statins), lifestyle interventions (e.g., salt reduction, smoking cessation)	Incremental cost-effectiveness ratio (ICER) analysis
Ortegón et al. [53]	2012	Multiple (Sub-Saharan Africa, regional focus)	Decision-Analytic Model	Cardiovascular disease events (combined), cardiovascular mortality	Pharmacologic treatments (e.g., antihypertensives, statins), lifestyle interventions (e.g., salt reduction, smoking cessation)	Incremental cost-effectiveness ratio (ICER) analysis, disability-adjusted life years (DALYs) averted
Yokobori et al. [54]	2024	Zambia	Decision-Analytic Model	Acute myocardial infarction (AMI), coronary heart disease (CHD), stroke, cardiovascular mortality	Pharmacologic treatment of hypertension	Incremental cost-effectiveness ratio (ICER) analysis
Reiker et al. [55]	2023	Senegal	Decision-Analytic Model	Cardiovascular events, cardiovascular mortality, disability-adjusted life years (DALYs) averted	CARDIO4Cities program (improved hypertension management through enhanced screening, treatment, and control)	Incremental cost-effectiveness ratio (ICER) analysis
Rosendaal et al. [56]	2016	Nigeria	Decision-Analytic Model	Cardiovascular disease events (combined), cardiovascular mortality	Hypertension treatment strategies (pharmacologic interventions)	Incremental cost-effectiveness ratio (ICER) analysis
Sacco et al. [57]	2016	Multiple (Sub-Saharan Africa, regional focus)	Life Table / Multi-State Model	Cardiovascular disease events, CVD mortality, disability-adjusted life years (DALYs)	Reduction in key risk factors (e.g., smoking, salt intake, hypertension, obesity) to meet WHO 25x25 targets	
Wyk et al. [58]	2021	South Africa	Life Table / Multi-State Model	Stroke, diabetes, prevalence years lived with disability (PYLDs), incident years lived with disability (YLDs)	None	
Subramanian et al. [31]	2019	Kenya	Microsimulation Model	Stroke, Coronary Heart Disease (CHD), Acute Myocardial Infarction (MI), Angina, Cardiac Arrest	Risk-stratified medication management for hypertension	Incremental cost-effectiveness ratio (ICER) analysis, disability-adjusted life years (DALYs) averted
Oamen et al. [32]	2022	Nigeria	Decision-Analytic Model	Hypertension management costs and outcomes (indirectly related to CVD risk reduction)	Hypertension management (pharmacological and non-pharmacological interventions)	Cost analysis using descriptive statistics and Microsoft Excel
				Cardiovascular	Gradual reduction of sodium content in high-salt foods; Public	

https://dx.doi.org/10.4314/mmj.v38i1.6

Table 1 Cont...

Bertram et al. [33]	2012	South Africa	Decision-Analytic Model	Cardiovascular disease events (e.g., stroke, myocardial infarction) averted	Gradual reduction of sodium content in high-salt foods; Public health campaigns to reduce discretionary salt use	Incremental cost-effectiveness ratio (ICER), cost per DALY averted
Mason et al. [34]	2016	Tunisia	Named/Other Model	Coronary heart disease (CHD) events averted, deaths averted	Mandatory salt reduction in processed foods; Health promotion campaigns to reduce discretionary salt use	Incremental cost-effectiveness ratio (ICER), cost per DALY averted
Verguet et al. [59]	2015	Ethiopia	Microsimulation Model	Cardiovascular disease events (e.g., myocardial infarction, stroke) averted	Public sector primary care interventions (e.g., hypertension treatment, diabetes management); Comparison with no intervention	Incremental cost-effectiveness ratio (ICER), cost per DALY averted
Aminde et al. [60]	2020	Cameroon	Markov Model	Ischemic heart disease, ischemic stroke, hemorrhagic stroke, hypertensive heart disease	Mass media campaign, school-based education programme, low-sodium salt substitute	Generalized cost-effectiveness analysis approach
Ker et al. [61]	2008	South Africa	Microsimulation Model	Coronary heart disease (CHD) risk over 10 years	Various combinations of antihypertensives (perindopril-indapamide, amlodipine), statins (atorvastatin), and fibrate (bezafibrate)	Average cost-effectiveness ratios (ACER) and incremental cost-effectiveness ratios (ICER) calculated
Basu et al. [62]	2021	Tanzania	Microsimulation Model	Atherosclerotic cardiovascular disease (fatal/non-fatal myocardial infarction and stroke)	Diagnosis, treatment, and control of blood pressure, dyslipidaemia, and glycaemia among people with diabetes	Incremental cost-effectiveness ratio (ICER), cost per DALY averted
Tolla et al. [63]	2016	Ethiopia	Costing and Economic Model	Ischemic heart disease (IHD), stroke	15 single interventions and 16 integrated packages (primary prevention, acute treatment, secondary prevention)	Incremental cost-effectiveness ratio (ICER), cost per DALY averted
Wambiya et al. [64]	2021	Kenya, Uganda	Decision-Analytic Model	Cardiovascular disease outcomes related to cardiometabolic multimorbidity	Integrated care interventions for cardiometabolic multimorbidity (e.g., diabetes, hypertension, CVD)	Incremental cost-effectiveness ratio (ICER), cost per DALY averted, cost-utility analysis
Atibila et al. [65]	2024	Ghana	Markov Model	Hypertension-related outcomes (specific complications not detailed)	Routine care for hypertension management	Cost analysis using Markov model
Manyema et al. [66]	2016	South Africa	Life Table / Multi-State Model	Stroke mortality and morbidity	Sugar-sweetened beverage (SSB) tax	Change in prevalent stroke cases and annual deaths and health-adjusted life years averted over time
Mensah et al. [67]	2025	Multiple (Sub-Saharan Africa, regional focus)	Markov Model	Varies across studies (CHD, stroke, CVD events)	Salt reduction policies, alcohol pricing policies	cost-utility analysis, quality-adjusted life years (QALYs) gained and disability-adjusted life years (DALYs) averted
Watkins et al. [68]	2015	Multiple (Sub-Saharan Africa, regional focus)	Markov Model	Acute rheumatic fever (ARF), rheumatic heart disease (RHD), severe heart failure, stroke	Primary prevention, secondary prevention, surgical services scale-up	Incremental cost-effectiveness ratio (ICER), cost per DALY averted
Webb [69]	2024	South Africa	Markov Model	Cardiovascular disease events, stroke, mortality	Various CVD prevention strategies (single risk factor vs total risk approach)	Incremental cost-effectiveness ratio (ICER), cost per DALY averted

Table 1 Cont...

Cobiac et al.[70]	2016	Global (includes African countries)	Comparative Risk Assessment Model	Cardiovascular disease events, stroke, ischemic heart disease	Voluntary reformulation, mandatory reformulation, school-based education, mass media campaign, low-sodium salt substitute	Incremental cost-effectiveness ratio (ICER), cost per DALY averted
Henry-Lines[71]	2021	South Africa	Decision-Analytic Model	Atrial fibrillation complications, stroke, mortality	Radiofrequency ablation (RFA), anti-arrhythmic drug therapy (ADT)	Incremental cost-effectiveness ratio (ICER), cost per DALY averted

This process involves clearly outlining the goals and boundaries of the model, selecting appropriate evaluation methods, and incorporating equity considerations. It also includes choosing the right model type and structure, defining the interventions and outcomes of interest, and ensuring the model is built on accurate data. Validation and sensitivity testing are essential steps to confirm reliability, and finally, the results should be framed to support practical policy decisions.

Public health policy recommendations of current CVD models in Africa

Findings across studies consistently underscore the burden of untreated hypertension and hyperlipidemia as major contributors to premature mortality. Cost-effective solutions such as screening and treatment led by community health workers (e.g., Gaziano et al., 2015[36]), task-shifting strategies (e.g., Bovet et al., 2006[35]), and national procurement of generic medicines (e.g., Watkins et al., 2016[72]) were shown to produce significant health gains at low incremental cost. Furthermore, some studies (e.g., Pozo-Martin et al., 2021[37]; Robberstadet al., 2007[39]; Gaziano et al., 2015[36]; and Basu et al., 2019[70]) emphasized the role of contextualized interventions tailored to local health system capacities.

Most studies advocate for integration of CVD prevention into primary healthcare and Universal Health Coverage (UHC) frameworks. Recommendations include expanding essential NCD services through decentralized platforms (e.g., Bertram et al., 2021[68]), prioritizing cost-effective intervention bundles (e.g., Watkins et al., 2016[72]), and including cardiovascular medicines in essential drug lists. Several authors urge Ministries of Health to institutionalize data systems to support ongoing model updates and policy translation.

Strengths and limitations of current CVD models

The strengths of current CVD models in Africa include their growing reliance on nationally representative data, and incorporation of cost-effectiveness and policy relevance. Several models include sensitivity analyses and scenario-based forecasting, which enhance credibility and utility for decision-makers. Notable limitations were assumptions of perfect adherence, limited generalizability to rural settings, and incomplete integration of comorbidities or health system constraints (e.g., Ngalesoni et al., 20156[49]; Pozo-Martin et al.,2021[37]; Bosu et al., 2019[75]). Integration of comorbidities, system constraints, or gender and age dynamics is also limited. Very few models include equity metrics or track differential impacts across subgroups. Moreover, there is a notable absence of models tailored to humanitarian, fragile, or post-conflict settings, which are increasingly relevant in Africa. Another major gap is the under-representation of younger populations in modelling frameworks, despite the increasing risk of NCDs among adolescents and young adults.

This scoping review provides a comprehensive synthesis of 40 studies published between 2005 and 2025 that utilized mathematical models to estimate the impact of cardiovascular disease interventions and risk factors in Africa. The findings demonstrate a growing recognition of the utility of modelling in informing policy for NCDs. Most studies assessed the cost-effectiveness and health impact of pharmacological interventions (particularly antihypertensives and statins), as well as lifestyle modifications such as salt reduction, increased physical activity, and improved diet. Consistently, these models affirmed the effectiveness and affordability of primary prevention strategies, especially when implemented through community-level or task-shifted delivery mechanisms.

Importantly, the majority of models concluded that integrating CVD interventions into existing primary healthcare systems rather than relying on vertical, disease-specific approaches yields greater health benefits and cost savings. Combined intervention packages, particularly those targeting hypertension and hyperlipidemia simultaneously, were shown to prevent more cardiovascular events and deaths than single-focus strategies[76]. These findings support the movement toward integrated service delivery under Universal Health Coverage (UHC) frameworks[77]. However, many models assumed ideal implementation conditions, including high adherence and access. These assumptions may not reflect real-world contexts[13,78]. This highlights the need for models that incorporate delivery constraints, including stock-outs, workforce shortages, and financial limitations common realities in SSA health systems.

One major limitation identified across the included CVD modelling studies is the restricted geographic scope, with most models focused on South Africa, Nigeria, Kenya, and a few other middle-income countries. Fragile or underserved settings, including rural regions and low-income countries, remain severely underrepresented[79]. Moreover, very few models explicitly accounted for health equity, despite wide disparities in access to CVD care by income, gender, and location. Only a handful of studies explored the differential impact of interventions across subgroups, which is essential for designing pro-equity policies. Similarly, adolescent and youth populations were almost entirely excluded, despite growing CVD risk factor exposure in these demographic groups. Another limitation is that model validation and calibration to local data were inconsistently applied, raising concerns about generalizability and policy relevance. Many studies used global risk equations, such as Framingham or SCORE, which may over- or underestimate true CVD risk in African populations[80]. This emphasizes the need for more context-specific data, as well as local adaptation of models to reflect population-specific risk factor distributions and comorbidity profiles. Encouragingly, some more recent studies attempted local calibration using country-level WHO STEPS or demographic data, indicating a positive trend

towards data localization as in settings of Asia and Europe[81]. In light of these insights, a hybrid microsimulation model with embedded system dynamics components appears to be well-suited for the complex health systems in Africa[82]. However, the optimal modelling approach should be guided by the specific research question, as in some cases, a simpler model may be more appropriate and sufficient. Microsimulation allows for detailed modelling of individual heterogeneity, including age, sex, socioeconomic status, and comorbid conditions crucial in high-variability contexts like in Africa[34,82]. When integrated with system dynamics, the model can also simulate feedback loops, health system bottlenecks, and broader policy levels[83]. Such a model offers a pragmatic and flexible platform to evaluate multiple intervention scenarios over time, under varying assumptions of funding, service capacity, and patient behaviour[84]. Crucially, this structure can incorporate ethical and equity considerations by stratifying outcomes across population subgroups[84].

For programme planners and policymakers, these findings have several implications. First, models should be developed and used not only for academic inquiry but as embedded decision-support tools in national health planning processes[50,84]. Ministries of Health can use these models to help prioritize interventions in essential health packages, analyse fiscal space, and plan for the sustainable expansion of CVD services. However, it is important to use models carefully, as changing the inputs can lead to very different results. To ensure the findings are reliable, models should take uncertainty into account, and it is a good idea to have different experts run independent analyses. Involving implementers, communities, and frontline providers in co-developing the models is also crucial to ensure they are relevant, trusted, and aligned with local needs. Second, donors and technical partners should support regional modelling capacity through investments in data infrastructure, local training, and cross-country collaboration. A shared modelling platform or consortium could facilitate standardized approaches, reduce duplication, and accelerate evidence-informed policymaking[85] .

A key strength of this review lies in its comprehensive inclusion of studies published between 2007 and 2025, offering a longitudinal perspective on modelling evolution. The review spans diverse model types, data sources, and intervention strategies, thereby providing a broad understanding of methodological trends and regional applicability. By extracting granular data including model assumptions, calibration techniques, and economic evaluation components this study also enables a nuanced synthesis relevant to policymakers and researchers alike. However, the review has some limitations. First, the exclusion of non-English-language publications may have limited the inclusion of studies from francophone and lusophone African countries, potentially introducing language bias. In addition, the search was limited to PubMed and Google Scholar. Although these sources were chosen to balance biomedical coverage with broader retrieval of regionally relevant and less well-indexed literature, the omission of other databases such as Embase, Web of Science, Scopus, or African Index Medicus may have resulted in some relevant studies being missed. Lastly, given the heterogeneity of modelling approaches, it was not feasible to quantitatively compare model outcomes, limiting direct conclusions on effectiveness rankings. Despite these limitations, the review offers critical insights that can guide future research, model development, and policy engagement.

In conclusion, CVD modelling in Africa has made meaningful progress, but still falls short of its full potential to guide programmatic action. Existing models highlight the effectiveness and affordability of preventive strategies and the importance of integrated care, yet often fail to account for real-world constraints and inequities. To bridge this gap, future models should prioritize context-specific microsimulation frameworks that include system dynamics, incorporate local data, and reflect health system realities. Establishing a regional modelling platform comprising governments, academia, civil society, and global partners would enable shared learning, tool development, and knowledge exchange. This would allow countries to adopt and adapt models tailored to their specific needs, leading to smarter investments in CVD prevention and control. As the burden of NCDs rises and fiscal space narrows, modelling must become a cornerstone of national and regional CVD strategies. The way forward is clear: build context-sensitive, equity-focused, and policy-ready models that empower African countries to design, test, and implement the most impactful CVD interventions grounded in data, driven by local priorities, and aligned with UHC goals.

Author Contributions

WFN, JE, ASM and OK designed the study drawing on the design of our scoping review. All authors approved the final manuscript.

Funding Information

We received no funding to conduct this analysis.

Competing Interests

We declare that there are no competing interests. The paper was prepared as part of the Doctoral Studies in Global Health at University of Geneva.

References

1.Roth, G. A. et al. Global burden of cardiovascular diseases and risk factors, 1990–2019: update from the GBD 2019 study. J. Am. Coll. Cardiol. 76, 2982–3021 (2020).

2.Di Cesare, M. et al. The Heart of the World. Glob. Heart 19, 11 (2024).

3.Alhuneafat, L. et al. Burden of cardiovascular disease in Sub-Saharan Africa, 1990-2019: An analysis of the Global Burden of Disease Study. Curr. Probl. Cardiol. 49, 102557 (2024).

4.Gouda, H. N. et al. Burden of non-communicable diseases in sub-Saharan Africa, 1990-2017: results from the Global Burden of Disease Study 2017. Lancet Glob. Health 7, e1375–e1387 (2019).

5.Minja, N. W. et al. Cardiovascular diseases in Africa in the twenty-first century: Gaps and priorities going forward. Front. Cardiovasc. Med. 9, 1008335 (2022).

6.KA, M. M. et al. Promotion of Cardiovascular Health in Africa: The Alliance for Medical Research in Africa (AMedRA) Expert Panel. Promot. Glob. Cardiovasc. Health 3, 101376 (2024).

7.Chotchoungchatchai, S. et al. Primary health care and sustainable development goals. Bull. World Health Organ. 98, 792–800 (2020).

8.Garnett, G. P., Cousens, S., Hallett, T. B., Steketee, R. & Walker, N. Mathematical models in the evaluation of health programmes. The Lancet 378, 515–525 (2011).

9.Silal, S., Bardsley, C., Menon, R., Abdullahi, L. & White, L. Epidemiological modelling for public health decision making in sub-Saharan Africa A strategic plan for capacity strengthening. (2022).

10.Panovska-Griffiths, J., Kerr, C., Waites, W. & Stuart, R. Mathematical modeling as a tool for policy decision making: Applications to the COVID-19 pandemic. in Handbook of Statistics (2021). doi:10.1016/

bs.host.2020.12.001.

11.Lo, N. C. et al. Contribution and quality of mathematical modeling evidence in World Health Organization guidelines: A systematic review. Epidemics 39, 100570 (2022).

12.Martin-Moreno, J. M. et al. Predictive Models for Forecasting Public Health Scenarios: Practical Experiences Applied during the First Wave of the COVID-19 Pandemic. Int. J. Environ. Res. Public. Health 19, (2022).

13.Kruk, M. E. et al. High-quality health systems in the Sustainable Development Goals era: time for a revolution. Lancet Glob. Health 6, e1196–e1252 (2018).

14.Institute of Medicine (US) Committee on Preventing the Global Epidemic of Cardiovascular Disease: Meeting the Challenges in Developing Countries; Fuster V, Kelly BB, editors. Promoting Cardiovascular Health in the Developing World: A Critical Challenge to Achieve Global Health. Washington (DC): National Academies Press (US); 2010. 5, Reducing the Burden of Cardiovascular Disease: Intervention Approaches. Available from: https://www.ncbi.nlm.nih.gov/books/NBK45696/.

15.Levac, D., Colquhoun, H. & O'Brien, K. K. Scoping studies: advancing the methodology. Implement. Sci. IS 5, 69 (2010).

16.Arksey, H. & O'malley, L. Scoping studies: towards a methodological framework. Int. J. Soc. Res. Methodol. 8, 19–32 (2005).

17.Liberati, A. et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. J. Clin. Epidemiol. 62, e1-34 (2009).

18. Porgo, T. V. et al. The use of mathematical modeling studies for evidence synthesis and guideline development: A glossary. Res. Synth. Methods 10, 125–133 (2019).

19.Collins, J. H., Cambiano, V., Phillips, A. N. & Colbourn, T. Mathematical modelling to estimate the impact of maternal and perinatal healthcare services and interventions on health in sub-Saharan Africa: A scoping review. PLOS ONE 19, e0296540 (2024).

20.Office, U. N. S. Standard Country or Area Codes for Statistical Use. (UN, 1982).

21.Polanin JR, Pigott TD, Espelage DL, Grotpeter JK. Best practice guidelines for abstract screening large-evidence systematic reviews and meta-analyses. Res Synth Methods. 2019;10(3):330-342. doi:10.1002/jrsm.1354.

22.Hiebl, M. R. W. Sample Selection in Systematic Literature Reviews of Management Research. Organ. Res. Methods 26, 229–261 (2023).

23.Campbell, F. et al. Mapping reviews, scoping reviews, and evidence and gap maps (EGMs): the same but different— the "Big Picture" review family. Syst. Rev. 12, 45 (2023).

24.Booth, A., Sommer, I., Noyes, J., Houghton, C. & Campbell, F. Rapid reviews methods series: guidance on rapid qualitative evidence synthesis. BMJ Evid.-Based Med. 29, 194–200 (2024).

25.Paré G, Kitsiou S. Chapter 9 Methods for Literature Reviews. In: Lau F, Kuziemsky C, editors. Handbook of eHealth Evaluation: An Evidence-based Approach [Internet]. Victoria (BC): University of Victoria; 2017 Feb 27. Available from: https://www.ncbi.nlm.nih.gov/books/NBK481583/.

26.Naeem, M., Ozuem, W., Howell, K. & Ranfagni, S. A Step-by-Step Process of Thematic Analysis to Develop a Conceptual Model in Qualitative Research. Int. J. Qual. Methods 22, 16094069231205789 (2023).

27.Deeks JJ, Higgins JPT, Altman DG (editors). Chapter 10: Analysing data and undertaking meta-analyses. In: Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, Welch VA (editors). Cochrane Handbook for Systematic Reviews of Interventions version 6.2 (updated February 2021).

28.Page, M. J. et al. PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews. BMJ 372, n160 (2021).

29.Subramanian, S., Hilscher, R., Gakunga, R., Munoz, B. & Ogola, E. Cost-effectiveness of risk stratified medication management for reducing premature cardiovascular mortality in Kenya. PloS One 14, e0218256 (2019).

30.Oamen, T., Osemene, K. P. & Ihekoronye, M. Economic analysis of hypertension management in public hospitals in Southwestern Nigeria: evidence from secondary data analysis. 11, 1–11 (2022).

31.Bertram, M., Steyn, K., Wentzel-Viljoen, E., Tollman, S. & Hofman, K. Reducing the sodium content of high-salt foods: Effect on cardiovascular disease in South Africa. South Afr. Med. J. Suid-Afr. Tydskr. Vir Geneeskd. 102, 743–5 (2012).

32.Mason, H. et al. A cost effectiveness analysis of salt reduction policies to reduce coronary heart disease in four Eastern Mediterranean countries. PloS One 9, e84445 (2014).

33.Bertram, M. Y. et al. Cost-Effectiveness of Population Level and Individual Level Interventions to Combat Non-communicable Disease in Eastern Sub-Saharan Africa and South East Asia: A WHO-CHOICE Analysis. Int. J. Health Policy Manag. 10, 724–733 (2021).

34.Basu, S., Wagner, R. G., Sewpaul, R., Reddy, P. & Davies, J. Implications of scaling up cardiovascular disease treatment in South Africa: a microsimulation and cost-effectiveness analysis. Lancet Glob. Health 7, e270–e280 (2019).

35.Bovet, P., Shamlaye, C., Gabriel, A., Riesen, W. & Paccaud, F. Prevalence of cardiovascular risk factors in a middle-income country and estimated cost of a treatment strategy. BMC Public Health 6, 9 (2006).

36.Gaziano, T. et al. Cardiovascular Disease Screening By Community Health Workers Can Be Cost-Effective In Low-Resource Countries. Health Aff. Proj. Hope 34, 1538–1545 (2015).

37.Pozo-Martin, F. et al. Cost-effectiveness of a Community-based Hypertension Improvement Project (ComHIP) in Ghana: results from a modelling study. BMJ Open 11, e039594 (2021).

38.Correction: Cost-effectiveness of a Community-based Hypertension Improvement Project (ComHIP) in Ghana: results from a modelling study. BMJ Open 11, e039594corr1 (2021).

39.Robberstad, B., Hemed, Y. & Norheim, O. F. Cost-effectiveness of medical interventions to prevent cardiovascular disease in a sub-Saharan African country--the case of Tanzania. Cost Eff. Resour. Alloc. CE 5, 3 (2007).

40.Ekwunife, O. I., Okafor, C. E., Ezenduka, C. C. & Udeogaranya, P. O. Cost-utility analysis of antihypertensive medications in Nigeria: a decision analysis. Cost Eff. Resour. Alloc. CE 11, 2 (2013).

41.Abdelhamid, M. et al. Dapagliflozin cost-effectiveness analysis in heart failure patients in Egypt. J. Med. Econ. 25, 450–456 (2022).

42.D'Couto, H. et al. The impact of tobacco smoking and smoking cessation on lung cancer and stroke incidence among people with HIV on antiretroviral therapy in South Africa: a simulation modeling study. BMJ Glob. Health 9, (2024).

43.Dugas, L. R. et al. Cardiovascular risk status of Afro-origin populations across the spectrum of economic development: findings from the Modeling the Epidemiologic Transition Study. BMC Public Health 17, 438 (2017).

44.Rosendaal, N. T. A. et al. Costs and Cost-Effectiveness of Hypertension Screening and Treatment in Adults with Hypertension in Rural Nigeria in the Context of a Health Insurance Program. PloS One 11, e0157925 (2016).

45.Gaziano, T. A., Steyn, K., Cohen, D. J., Weinstein, M. C. & Opie, L. H. Cost-effectiveness analysis of hypertension guidelines in South Africa: absolute risk versus blood pressure level. Circulation 112,

3569–3576 (2005).

46.Hickey, M. D. et al. Cost-effectiveness of leveraging existing HIV primary health systems and community health workers for hypertension screening and treatment in Africa: an individual-based modelling study. medRxiv : the preprint server for health sciences 2024.08.14.24312004 Preprint at https://doi.org/10.1101/2024.08.14.24312004 (2024).

47.Kasaie, P. et al. Integrated screening and treatment services for HIV, hypertension and diabetes in Kenya: assessing the epidemiological impact and cost-effectiveness from a national and regional perspective. J. Int. AIDS Soc. 23 Suppl 1, e25499 (2020).

48.Lin, J. K. et al. Cost-effectiveness of a fixed-dose combination pill for secondary prevention of cardiovascular disease in China, India, Mexico, Nigeria, and South Africa: a modelling study. Lancet Glob. Health 7, e1346–e1358 (2019).

49.Ngalesoni, F. N., Ruhago, G. M., Mori, A. T., Robberstad, B. & Norheim, O. F. Cost-effectiveness of medical primary prevention strategies to reduce absolute risk of cardiovascular disease in Tanzania: a Markov modelling study. BMC Health Serv. Res. 16, 185 (2016).

50.Oguta, J. O. et al. Application of decision analytic modelling to cardiovascular disease prevention in Sub-Saharan Africa: a systematic review. Commun. Med. 5, 46 (2025).

51.Ortegón, M., Lim, S., Chisholm, D. & Mendis, S. Cost effectiveness of strategies to combat cardiovascular disease, diabetes, and tobacco use in sub-Saharan Africa and South East Asia: mathematical modelling study. BMJ 344, e607 (2012).

52.Yokobori, Y., Deidda, M. & Manca, F. Pharmaceutical intervention for hypertension in a rural district of the Republic of Zambia: a model-based economic evaluation. BMJ Open 14, e084575 (2024).

53.Reiker, T. et al. Population health impact and economic evaluation of the CARDIO4Cities approach to improve urban hypertension management. PLOS Glob. Public Health 3, e0001480 (2023).

54.Sacco, R. L. et al. The Heart of 25 by 25: Achieving the Goal of Reducing Global and Regional Premature Deaths From Cardiovascular Diseases and Stroke: A Modeling Study From the American Heart Association and World Heart Federation. Circulation 133, e674-690 (2016).

55.Pillay-van Wyk, V. et al. Can non-fatal burden estimates from the Global Burden of Disease study be used locally? An investigation using models of stroke and diabetes for South Africa. Glob. Health Action 14, 1856471 (2021).

56.Verguet, S. et al. Health gains and financial risk protection afforded by public financing of selected interventions in Ethiopia: an extended cost-effectiveness analysis. Lancet Glob. Health 3, e288–e296 (2015).

57.Aminde, L. N., Cobiac, L. & Veerman, J. L. Cost-effectiveness analysis of population salt reduction interventions to prevent cardiovascular disease in Cameroon: mathematical modelling study. BMJ Open 10, e041346 (2020).

58.Ker, J. A., Oosthuizen, H. & Rheeder, P. Decision-making using absolute cardiovascular risk reduction and incremental cost-effectiveness ratios: a case study: cardiovascular topics. Cardiovasc. J. Afr. 19, 97–101 (2008).

59.Basu, S. et al. Estimated effect of increased diagnosis, treatment, and control of diabetes and its associated cardiovascular risk factors among low-income and middle-income countries: a microsimulation model. Lancet Glob. Health 9, e1539–e1552 (2021).

60.Tolla, M. T. et al. Prevention and treatment of cardiovascular disease in Ethiopia: a cost-effectiveness analysis. Cost Eff. Resour. Alloc. 14, 1–14 (2016).

61.Wambiya, E. O. et al. Application of decision-analytic models to inform integrated care interventions for cardiometabolic multimorbidity: A systematic review. medRxiv 2024.10. 19.24315798 (2024).

62.Manyema, M., Veerman, L. J., Tugendhaft, A., Labadarios, D. & Hofman, K. J. Modelling the potential impact of a sugar-sweetened beverage tax on stroke mortality, costs and health-adjusted life years in South Africa. BMC Public Health 16, 1–10 (2016).

63.Mensah, J. P., Thomas, C., Akparibo, R. & Brennan, A. Public health economic modelling in evaluations of salt and/or alcohol policies: a systematic scoping review. BMC Public Health 25, 82 (2025).

64.Watkins, D., Lubinga, S. & Babigumira, J. Strategies for prevention and control of rheumatic fever and rheumatic heart disease in Sub-Saharan Africa: a preliminary cost-effectiveness analysis. Ann. Glob. Health 81, 102–103 (2015).

65.Webb, M. W. Population Strategies to Decrease Sodium Intake: A Global Cost-Effectiveness Analysis. (2012).

66.Smith-Spangler, C. M., Juusola, J. L., Enns, E. A., Owens, D. K. & Garber, A. M. Population strategies to decrease sodium intake and the burden of cardiovascular disease: a cost-effectiveness analysis. Ann. Intern. Med. 152, 481–487 (2010).

67.Henry-Lines, H. Cost-effectiveness analysis of radiofrequency ablation versus drugs for the treatment of a trial fibrillation in the South African population. (Stellenbosch: Stellenbosch University, 2021).

68.Bertram, M. Y. et al. Cost-Effectiveness of Population Level and Individual Level Interventions to Combat Non-communicable Disease in Eastern Sub-Saharan Africa and South East Asia: A WHO-CHOICE Analysis. Int. J. Health Policy Manag. 10, 724–733 (2021).

69.Kumar, A., Siddharth, V., Singh, S. I. & Narang, R. Cost analysis of treating cardiovascular diseases in a super-specialty hospital. PloS One 17, e0262190 (2022).

70.Basu, S., Wagner, R. G., Sewpaul, R., Reddy, P. & Davies, J. Implications of scaling up cardiovascular disease treatment in South Africa: a microsimulation and cost-effectiveness analysis. Lancet Glob. Health 7, e270–e280 (2019).

71.Correction: Cost-effectiveness of risk stratified medication management for reducing premature cardiovascular mortality in Kenya. PloS One 15, e0233139 (2020).

72.Watkins, D. A., Olson, Z. D., Verguet, S., Nugent, R. A. & Jamison, D. T. Cardiovascular disease and impoverishment averted due to a salt reduction policy in South Africa: an extended cost-effectiveness analysis. Health Policy Plan. 31, 75–82 (2016).

73.Bigna, J. J. & Noubiap, J. J. The rising burden of non-communicable diseases in sub-Saharan Africa. Lancet Glob. Health 7, e1295–e1296 (2019).

74.Pichon-Riviere, A., Drummond, M., Palacios, A., Garcia-Marti, S. & Augustovski, F. Determining the efficiency path to universal health coverage: cost-effectiveness thresholds for 174 countries based on growth in life expectancy and health expenditures. Lancet Glob. Health 11, e833–e842 (2023).

75.Basu, S., Wagner, R. G., Sewpaul, R., Reddy, P. & Davies, J. Implications of scaling up cardiovascular disease treatment in South Africa: a microsimulation and cost-effectiveness analysis. Lancet Glob. Health 7, e270–e280 (2019).

76.Jeemon P, Gupta R, Onen C, et al. Management of Hypertension and Dyslipidemia for Primary Prevention of Cardiovascular Disease. In: Prabhakaran D, Anand S, Gaziano TA, et al., Editors. Cardiovascular, Respiratory, and Related Disorders. 3rd Edition. Washington (DC): The International Bank for Reconstruction and Development / The World Bank; 2017 Nov 17. Chapter 22. Available from: Https://Www.Ncbi.Nlm.Nih.Gov/Books/NBK525163/ Doi: 10.1596/978-1-4648-0518-9_ch22.

77.Sacks, E., Schleiff, M., Were, M., Chowdhury, A. M. & Perry, H. B. Communities, universal health coverage and primary health care. Bull. World Health Organ. 98, 773–780 (2020).

78.Kruk, M. E. et al. High-quality health systems in the Sustainable Development Goals era: time for a revolution. Lancet Glob. Health 6, e1196–e1252 (2018).

79.Anand, S. et al. Social disadvantage and cardiovascular disease: Development of an index and analysis of age, sex, and ethnicity effects. Int. J. Epidemiol. 35, 1239–45 (2006).

80.Boateng, D. et al. Cardiovascular disease risk prediction in sub-Saharan African populations-Comparative analysis of risk algorithms in the RODAM study. Int. J. Cardiol. 254, (2018).

81.Collins, D., Laatikainen, T. & Farrington, J. Implementing essential interventions for cardiovascular disease risk management in primary healthcare: lessons from Eastern Europe and Central Asia. BMJ Glob. Health 5, e002111 (2020).

82.Darabi, N. & Hosseinichimeh, N. System Dynamics Modeling in Health and Medicine: A Systematic Literature Review. Syst. Dyn. Rev. 36, (2020).

83.Hirsch, G., Homer, J., Evans, E. & Zielinski, A. A system dynamics model for planning cardiovascular disease interventions. Am. J. Public Health 100, 616–622 (2010).

84.Peng, C. Q. et al. Gazing through time and beyond the health sector: Insights from a system dynamics model of cardiovascular disease in Australia. PLOS ONE 16, e0257760 (2021).

85.Pan American Health Organization and Organisation for Economic Co-Operation and Development. 2015. Applying Modeling to Improve Health and Economic Policy Decisions in the Americas: The Case of Noncommunicable Diseases. Washington, D.C.: PAHO.

86.Correction: Costs and Cost-Effectiveness of Hypertension Screening and Treatment in Adults with Hypertension in Rural Nigeria in the Context of a Health Insurance Program. PloS One 11, e0162421 (2016).

87.Wambiya, E. O. et al. Application of decision-analytic models to inform integrated care interventions for cardiometabolic multimorbidity: A systematic review. medRxiv 2024.10. 19.24315798 (2024).

S1 File: PRISMA-ScR checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	1
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	2-3
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	3-5
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	5
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	N/A
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	6-7
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed	7-8
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	7-9
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	9
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	9-10
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	9-10 & Supporting information (S2 File)
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	N/A
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	9-10
RESULTS			

Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	11
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	Supporting information (S2 File)
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	N/A
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	Supporting information (S2 File)
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	11-21
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	22-27
Limitations	20	Discuss the limitations of the scoping review process.	28-29
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	29
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	N/A

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.

* Where sources of evidence (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.

† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with information sources (see first footnote).

‡ The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.

§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

From: Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMAScR): Checklist and Explanation. Ann Intern Med. 2018;169:467–473. doi: 10.7326/M18-0850.

S2 File: Data extraction form to be used in scoping review for cardiovascular disease mathematical modelling

Category	Questions
Study characteristics	• Who are the authors, and when was the study published? • Which countries in sub-Saharan Africa does the study focus on?
Model characteristics	• What type of mathematical model is used (e.g., Markov models, microsimulation, compartmental models, system dynamics or their combinations)?
Data inputs	• What are the primary data sources (e.g., population surveys, national health registries, randomized trials, systematic reviews)? • Are local, regional, or global data used, and how were they adapted to the SSA context? • Were assumptions made for missing or unavailable data?
CVD outcomes	• What specific CVD outcomes are modelled (e.g., mortality, morbidity, quality-adjusted life years [QALYs], disability-adjusted life years [DALYs])? • Are short-term or long-term outcomes assessed?
Interventions and risk factors	• Which interventions are modelled (e.g., aspirin, statins, lifestyle interventions)? • What risk factors are included (e.g., hypertension, diabetes, physical inactivity)? • Are multiple interventions or risk factors combined or analysed independently?
Model validation and calibration	• Was the model calibrated? If yes, how? • Was the model validated? If yes, how? • Were sensitivity or uncertainty analyses performed?
Findings and implications	• What are the key findings of the study? • What is the policy or programmatic implications of the findings? • Were specific recommendations made for implementation in SSA?
Economic evaluation	• Were economic analyses performed? • What costs were considered (e.g., direct medical costs, societal costs)? • Detailed description of the methods used for economic evaluations
Strengths, assumptions, and limitations	• What are the stated strengths and limitations of the model? • What assumptions were made in the modelling process? • Were ethical or equity considerations mentioned?
Research gaps	• What gaps in knowledge or evidence were identified by the study? • Are there recommendations for future research?

S3 File: See attached MS Excel file with raw data

Box 1: Search terms used in the scoping review

Database	Search terms
PubMed	((“cardiovascular disease” OR CVD OR “heart disease” OR stroke OR “ischemic heart disease” OR “coronary artery disease” OR atherosclerosis OR “myocardial infarction” OR “heart failure”) AND (“mathematical model” OR “predictive model” OR “simulation model” OR “risk model” OR “decision model” OR “cost-effectiveness model” OR “Markov model” OR “Bayesian model” OR “machine learning model” OR “data-driven model” OR ((mathematical OR disease OR microsimulation OR deterministic OR stochastic OR compartment* OR “individual-based” OR “agent-based” OR “discrete-event” OR “time to event” OR “system dynamics” OR “Monte Carlo” OR “Markov chain” OR simulation) AND (model* OR simulat*))) AND (Africa OR “sub-Saharan Africa” OR Angola OR Benin OR Botswana OR “Burkina Faso” OR Burundi OR “Cabo Verde” OR Cameroon OR “Central African Republic” OR Chad OR Congo OR Comoros OR “Cote d’Ivoire” OR “Democratic Republic of the Congo” OR Djibouti OR Eswatini OR Eritrea OR Ethiopia OR “Equatorial Guinea” OR 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 Mauritius OR Mozambique OR Namibia OR Niger OR Nigeria OR Rwanda OR “Sao Tome and Principe” OR Senegal OR Seychelles OR “Sierra Leone” OR Somalia OR “South Africa” OR “South Sudan” OR Tanzania OR Togo OR Uganda OR Zambia OR Zimbabwe)) AND (“2000”[Date - Publication] : “3000”[Date - Publication])
Google Scholar	intitle:(Africa OR “sub-Saharan Africa” OR Angola OR Benin OR Botswana OR “Burkina Faso” OR Burundi OR “Cabo Verde” OR Cameroon OR “Central African Republic” OR Chad OR Congo OR Comoros OR “Cote d’Ivoire” OR “Democratic Republic of the Congo” OR Djibouti OR Eswatini OR Eritrea OR Ethiopia OR “Equatorial Guinea” OR 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 Mauritius OR Mozambique OR Namibia OR Niger OR Nigeria OR Rwanda OR “Sao Tome and Principe” OR Senegal OR Seychelles OR “Sierra Leone” OR Somalia OR “South Africa” OR “South Sudan” OR Tanzania OR Togo OR Uganda OR Zambia OR Zimbabwe) “CVD” “stroke” “heart disease” “cost-effectiveness” “simulation”