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Capturing Complexities in Urban Maternal and Newborn Healthcare Systems: A Scoping Review on Application of System Dynamics Modelling

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Abstract

Healthcare systems in urban areas are shaped by complex interactions between socioeconomic, infrastructure-related and governance factors. System Dynamics Modelling (SDM) offers a valuable approach to explore how these interrelated elements shape health outcomes, yet its application in maternal and newborn health (MNH) remains limited. We conducted a scoping review to synthesise the application of SDM in healthcare and examine how elements and discontinuities are incorporated to inform an urban MNH SDM. Following the PRISMA-ScR reporting guidelines, we searched PubMed, Cochrane Library, EMBASE, Web of Science, and Scopus. Of 10,900 records identified, 32 studies published between 2009 and 2025 were included, with 69% published after 2020. Included studies reflected six healthcare fields, with a third focusing on MNH (31%). Most SDM frameworks were conceptualized de novo (71%), with 29% adapted, and based on primary (93%) and secondary (63%) data. A qualitative SDM approach dominated (75%), followed by mixed methods (19%) and quantitative only (6%). Most studies (81%) utilised causal loop diagrams (CLDs); 19% additionally used stock-and-flow diagrams to investigate their research question. Among ten MNH studies, we grouped elements into six sub-systems and generated a CLD illustrating their relationships, serving as a basis for developing SDMs that have implications for policy.

Introduction

Despite living in urban areas, many women, especially the poorest living in informal settlements, struggle to access timely and quality maternal healthcare [1]. Long travel times and waiting times, overcrowded facilities, ineffective referrals, financial barriers to care, and a shortage of highly trained healthcare providers hinder timely access to care of adequate quality [1–4]. Urban areas often have stark socioeconomic disparities, and urban maternal healthcare systems are inherently complex and dynamic due to the multitude of elements that influence maternal health outcomes. These systems are shaped by various interconnected elements, including access to healthcare, socioeconomic status, political environment, governance, policy frameworks, and infrastructure [5]. Further, in urban settings, high population density, diverse communities, and unequal resource distributions create the conditions for significant health disparities, with marginalised populations experiencing higher rates of maternal mortality and morbidity [6].

A number of events disrupt the urban maternal health system, through breaks in the normal flow or operation of the system caused by sudden changes or by events such as population movements, natural disasters, policy changes, economic crises or advancements in technology. These disruptions unfold more rapidly in urban areas due to high population density, greater mobility and tightly interconnected service delivery. Collectively, we refer to these events as discontinuities. Thus, in this paper, a discontinuity is any event occurring at the community, health facility, city, sub-region, country and global level that is likely to have impact on the provision and use of (maternal and newborn) healthcare services. These discontinuities lead to either stability or instability and require adaptive measures to restore functionality in the provision and utilisation of maternal and newborn health (MNH) services in urban areas [1, 2]. Due to these complex interconnected drivers between disruptive events and health disparities, it is essential that we study urban MNH systems. This will allow developing of evidence-based strategies to address the root causes of such disparities and mechanisms through which disruptions influence the system [2]. Understanding the systemic issues that contribute to poor maternal and newborn health outcomes in urban areas will enable policymakers and healthcare providers to implement more effective and sustainable interventions tailored to the unique challenges faced by women and babies in urban settings [7].

The complexity of health systems (usually described as consisting of a number of interrelated constituent parts, with variables across multiple levels, i.e., interconnected drivers [8]) in urban areas makes it challenging to understand the pathways to the mechanisms which produce maternal health outcomes using traditional linear approaches. As a result, conclusions or policy implications drawn from such linear approaches maybe misdirected and/or ineffective [8]. For instance, conventional approaches such as observed (cohort or case-control study) or controlled interventions (randomised control trials), which deal with the complexity by breaking the issue into simple parts to be observed or controlled, have limited capacity to capture the complex interactions between social determinants of health and their effects on maternal health outcomes as a whole [8]. Therefore, reducing maternal and newborn mortality and morbidity in urban areas requires a comprehensive approach that considers this complex interplay by abstracting key system elements and discontinuities and simulating their dynamic interrelationships.

System dynamic modelling (SDM) is a particularly well-suited and powerful tool for studying the complexities of urban maternal healthcare systems due to its ability to disentangle the complex dynamics and pathways to utilization and delivery of healthcare services [8]. SDM can be used to capture and investigate holistic drivers for health system behaviour through models that can simulate the interactions among various components of the healthcare system over time, offering a comprehensive view of how various elements influence maternal health outcomes [6, 9].

System dynamic (SD) encompasses both qualitative and quantitative approaches, each serving distinct yet complementary purposes. Qualitative system dynamics focuses on understanding the structure and feedback mechanisms within complex systems through tools like causal loop diagrams (CLDs), which help conceptualize relationships without requiring quantitative parameterisation or simulation [10]. This approach is particularly valuable in the early stages of model development or when data are scarce. Quantitative system dynamics involves the use of stock and flow diagrams (SFD) and differential equations to simulate system behaviour over time, enabling rigorous analysis and policy testing [11]. As Richardson (1991) and Lane (1999) highlight, diagramming conventions play a crucial role in bridging qualitative insights with quantitative rigor, allowing for a more holistic understanding of dynamic systems [12] [13].

SDM enables the study of both short and long-term effects on MNH services and enables scenario testing to anticipate potential MNH outcomes and avoid negative side effects [14]. Furthermore, it facilitates scenario analysis, allowing researchers in consultation with key stakeholders like policymakers to test the potential impact of different interventions before implementation, ensuring that resources are used effectively and efficiently to improve maternal health [15]. By leveraging the strengths of SDM, we can develop more accurate and actionable insights into urban maternal healthcare systems, ultimately leading to better health outcomes for mothers and their newborns in urban areas [2].

To our knowledge, there has not been a comprehensive review of how SDM has been applied to investigate research questions related to discontinuities or events in MNH in cities or urban areas. A previous scoping review in this domain [19] had a narrow scope where system dynamics (SD) approaches including

qualitative diagrams and conceptual models (as well as quantitative SDM), had been used to investigate only questions related to maternal and child health (MCH) workforce planning. There remains a critical need for a comprehensive review of previous research in this area, to better understand how such models have been developed and what implications can be derived from the studies regarding discontinuities and associated pathways to impact on key maternal and newborn health outcomes specifically in urban settings.

Therefore, this study aims to synthesize existing research on SDM [20], methodological approaches (including approach to incorporation of key phenomena and elements), and discontinuities influencing the dynamics of urban health systems. Specifically, the objectives of this study are to: (i) identify the SDM methodological approaches employed across healthcare research in urban settings; (ii) describe the key elements and discontinuities captured in existing literature and how they affect the utilisation or provision of MNH in urban areas; and (iii) describe the pathways and mechanisms through which these key elements and discontinuities influence maternal and newborn healthcare systems, visualised using a CLD.

Methods

Study design, protocol and registration

This study is a scoping review synthesising existing research on SDM methodological approaches and the discontinuities that influence the dynamics of urban health systems, with a specific focus on MNH in urban settings. The scoping review protocol was registered on the Open Science Framework platform [21] to promote methodological transparency. The review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis extension for Scoping Reviews (PRISMA-ScR) reporting guidelines to ensure methodological rigour in the reporting of the review process and results [22, 23].

Eligibility criteria

Articles describing empirical studies applying SDM to investigate research questions in the field of urban health systems, as well as those addressing peri-urban or mixed urban–rural areas in any field of healthcare, were eligible for this review. However, when qualitatively conceptualising urban maternal and newborn healthcare systems using SDM (visualised using a CLD), we considered the subset of articles focusing on MNH. This narrower focus was necessary to ensure that the conceptualised CLD reflected urban MNH specific care pathways, which differ from other fields of health. Eligibility was further restricted to articles in English or French due to the language constraints of the review team, with non-peer-reviewed articles excluded (see Table 1 for complete study inclusion and exclusion criteria).

Table 1
Inclusion and Exclusion Criteria

Methodology	Inclusion	Exclusion
	Studies that make use of system dynamic modelling and present either a causal loop diagram or a stock and flow diagram.	**Studies that do not employ system dynamic modelling.**
Setting	Only studies focusing on healthcare or healthcare systems in urban and mixed urban-rural settings such as cities, densely populated areas, conurbations, etc.	Studies that do not focus on urban healthcare or healthcare systems or specifically address only rural or remote areas.
Topic	Health outcomes, healthcare access, health policy implementation, provision of healthcare, and healthcare utilisation indicators.	Studies not focusing on health/healthcare related topics (e.g. food security/ agriculture kind of literature, manufacturing, marketing (supply and demand), mining, engineering, ecological, etc).
Publication type	Peer-reviewed studies published until 10th April 2025.	Reports, commentaries and editorials, conference abstracts and non-peer-reviewed articles.
Language	Published in English and French.	Written in a language other than English or French.

Information Sources and Search strategy

Searches were conducted in five major databases: Scopus, Web of science, PubMed, Cochrane Library and EMBASE for articles published up to 10th April 2025. The search strategy was iteratively guided by the population (healthcare services), concept (system dynamic modelling), and context (urban setting) (PCC) framework recommended by the Joanna Briggs Institute [24]. The search strategy used for each database is presented in the supplementary materials, additional file 1.

Selection of sources of evidence and process

Key study information, such as study title, author list and abstract were retrieved from database searches and imported into the Covidence systematic review management tool to remove duplicates [25]. Covidence also tracked and backed up all screening activities, including title and abstract screening, full-text screening and generating the PRISMA flowchart. After removing duplicates automatically by Covidence software [25] and manually identifying others by RKO and AS, two-stage screening was performed: the first was title and abstract screening, and the second was full-text screening, during which articles were excluded or included based on the criteria outlined in Table 1. The articles were independently double-screened by three reviewers (RKO, AS, and NY) while PMM resolved any conflicts. The review decision process was reported using an adapted PRISMA-ScR flow diagram [23].

Data Extraction

Data was extracted through a standardized data extraction in Microsoft Excel spreadsheet. We extracted data on: Basic study characteristics (such as author list, year of publication, country(ies) of study, the city or urban area/region, journal or source, funding); Study and model methodology (healthcare context, outcome of interest, data source, modelling approach used (qualitative diagrams namely CLDs, SFDs or other conceptual model or quantitative SDM); key elements and discontinuities included in the model; mechanisms and pathways, model development process, model validation and testing methods and software used) and findings and implications (limitation of the model, applications and use (i.e., decision making or policy development or strategic planning)) and areas for future research.

Data Synthesis

The extracted data were synthesised using descriptive statistics and thematic groups, especially categorisation of the methodological approaches used in SDM across the studies identified. We explored characteristics such as the number of SDM studies over time and the spatial distribution of countries where the studies were conducted. Counts and percentages were used to describe the categorical data on methodological approaches and the specific health areas of application. The key elements of urban healthcare systems and discontinuities were analysed thematically to identify common themes. The pathways and mechanisms through which these key elements and discontinuities disrupt maternal healthcare systems were also summarised. We also outlined the limitations associated with implementing and utilizing SDM within urban healthcare systems.

Conceptualisation of an urban MNH system model

The review was conducted with a broad health systems scope to capture how SDM has been used across different health domains. During the full-text screening process, non-MNH studies were identified to provide transferable conceptual or methodological insights relevant to MNH. The MNH-specific focus was introduced at the conceptualisation stage, where insights from the broader literature were synthesised and contextualised to inform the development of the CLD.

To initiate model conceptualisation, we examined the CLDs and SFDs in the identified studies, focusing on key elements and relationships that comprise an involving urban MNH systems. We also considered any additional elements that could be relevant to urban MNH from the studies that had focused on health topics other than MNH. These elements were then integrated to conceptualise an SDM in the form of a CLD that links key elements and discontinuities within urban MNH systems and illustrates their influence on maternal and newborn health outcomes.

Results

Study Selection

We identified 10,900 articles from the five databases (Fig. 1). During deduplication, 3,355 articles were removed. The remaining 7,545 articles were screened at the title and abstract stage, and 6,788 articles were excluded for not meeting the inclusion criteria. The full-text review involved 757 studies; one full-text article was not accessible, and 724 articles were excluded after full-text screening. A total of 32 articles were included in the scoping review (Fig. 1).

Publication year and journal

The publication years of the 32 studies ranged from 2009 to 2025 (Fig. 2). The number of articles published annually increased over time, with a sharp increase between 2017/2019 and 2020/2022. The majority of the included studies (n = 22, 69%) were published within the last five years, i.e., 2020 to 2025.

Table 2
Summary of included studies (n = 32)

Authors	Country of study	Region	Setting (Urban/pre-urban/both)	Healthcare field	Modelling approach	Model building process	Diagram used	Model validation	Ap an mo
Ager, A. K., et al. (2015) [26]	Nigeria	Yobe state	Urban and rural	Primary health care	Qualitative	Conceptualized the framework, participatory approach stakeholders, literature review	CLD	Stakeholder workshop, data triangulation	Ma dri phe inf pol em pre
Ahmad, R., et al. (2019) [27]	Pakistan	Punjab	Urban and rural	Maternal and Newborn Healthcare	Qualitative and Quantitative	Conceptualized the framework, literature review, expert refinement,	CLD and SFD	Academic literature, expert opinion, boundary-adequacy test, extreme condition test, dimensional-consistency test performed	To unc the pro hea pla inf pol
Baugh Littlejohns, L., et al. (2018) [28]	Australia	South Australia	Urban and Rural	Multisectoral health system	Qualitative	Adapted existing framework	CLD	Internal iterative coding and consensus among researchers	Ma dri phe inf pol
Beenackers, M. A., et al. (2024) [29]	Netherlands	Dutch urban	Urban	Mental health	Qualitative	Adapted existing framework, expert refinement	CLD	Expert workshops	Ma dri phe str pla inf pol
Bensberg, M., et al. (2021) [30]	Australia	Victoria	Urban and Rural	Health promotion and prevention system	Qualitative	Adapted existing framework	CLD	Thematic analysis and triangulation among researchers, use of interpretative framework	Inf pol pro hea str
Bivona, E. and F. Cosenz (2017) [31]	Italy	Sicily	Urban and Rural	Maternal and Newborn Healthcare	Qualitative and Quantitative	Adapted existing framework, literature review	CLD and SFD	Historical data fit, scenario simulation	Inf pol pro hea str str pla
Cassidy, R., et al. (2021) [32]	Tanzania	Pwani	Urban and Rural	Maternal and Newborn Healthcare	Qualitative	Conceptualized the framework, participatory approach stakeholders	CLD	Stakeholder interviews, comparison of clds	Ma dri phe Inf pol pro hea str
Clarke, B., et al. (2021) [33]	Australia	Victoria	Urban and Rural	Obesity prevention	Qualitative	Adapted existing framework	CLD	Triangulation across interviews, documents, and observations; reviewed by multiple researchers	Ma dri phe pol imp
Das, P., et al. (2023) [34]	India	Madhya Pradesh	Urban and Rural	Immunization	Qualitative	Conceptualized the framework, participatory approach stakeholders, literature review	CLD	Stakeholder feedback, data triangulation	Inf pol pro hea str
Diaconu, K., et al. (2024) [35]	South Africa	Kwazuluu-Natal, Western Cape	Urban and Rural	Tuberculosis control and service delivery	Qualitative	Conceptualized the framework, participatory approach stakeholders	CLD	Stakeholder feedback, expert review	Inf pol pro hea str

Authors	Country of study	Region	Setting (Urban/pre-urban/both)	Healthcare field	Modelling approach	Model building process	Diagram used	Model validation	Ap an mo
									str pla
Elimian, K., et al. (2024) [36]	Nigeria	North-east Nigeria	Urban and Rural	Cholera intervention	Qualitative	Conceptualized the framework, participatory approach stakeholders	CLD	Iterative participant feedback; model verification with representatives	Inf pol pro hea str str pla
Hudani, A., et al. (2024) [37]	Canada	Toronto	Urban	Healthcare coordination	Qualitative	Adapted existing framework	CLD	Stakeholder workshop	Inf pol pro hea str
Hyder, A., et al. (2022) [38]	United States	Ohio	Urban	Maternal and Newborn Healthcare	Both Qualitative and Quantitative	Conceptualized the framework, participatory approach stakeholders	CLD	Participant feedback, iterative refinement, face validation during workshops	He pla pol eva
Jamal, Z., et al. (2020) [39]	Syria	Greater Damascus	Urban and Rural	Health service delivery	Qualitative	Conceptualized the framework, participatory approach stakeholders	CLD	Triangulation with reports, stakeholder feedback	Inf pol pro hea str em pre
Kanniyan, B., et al. (2021) [40]	India	Kerala	Urban	Immunization	Qualitative	Conceptualized the framework, participatory approach stakeholders	CLD	Stakeholder input	Inf pol pro hea str hea str
Leerapan, B., et al. (2021) [41]	Thailand	Bangkok, Nonthaburi	Urban	Universal Health Coverage	Both Qualitative and Quantitative	Conceptualized the framework, participatory approach stakeholders	CLD and SFD	Unit consistency test, structural validity test, behavioral replication test	Str pla pol eva
Lembani, M., et al. (2018) [42]	South Africa	Eastern Cape, Tambo district	Urban and Rural	Maternal and Newborn Healthcare	Qualitative	Conceptualized the framework, participatory approach stakeholders	CLD, Interrelationship Diagraphs (IRDs), Seed Model	Stakeholder feedback, triangulation	Str pla
Lemke, M. K., et al. (2023) [43]	United States	North texas	Urban	Maternal and Newborn Healthcare	Qualitative	Conceptualized the framework, participatory approach stakeholders	CLD	Member-checking sessions and participant feedback	Ma dri phe Inf pol pro hea str str pla
Liu, X., et al. (2020) [44]	China	Shanghai	Urban	Primary health care	Quantitative	Conceptualized the framework	CLD and SFD	Calibration with 2008–2013 data; validation using 2003 heat wave data	Po eva hea pla em pre
Marchal, B., et al. (2021) [45]	Georgia	Tbilisi	Urban	Tuberculosis control and service delivery	Qualitative	Conceptualized the framework, participatory approach stakeholders	CLD	Stakeholder feedback, triangulation with document review and interviews	Inf pol pro hea str str pla
Millar, L., et al. (2023) [46]	Australia	Western Australia	Urban and Rural	Primary health care	Qualitative	Conceptualized the framework, participatory approach stakeholders	CLD	Triangulation of gmb findings with survey data, cluster analysis of hlq	Inf pol pro hea str

Authors	Country of study	Region	Setting (Urban/pre-urban/both)	Healthcare field	Modelling approach	Model building process	Diagram used	Model validation	Ap an mo
								responses, stakeholder feedback sessions	str pla
Moustaid, E., et al. (2020) [47]	Sweden	Stockholm	Urban	Mental health	Qualitative	Conceptualized the framework, expert refinement,	CLD	Debrief session, expert interviews	Ma dri phe
Nguyen, L. K. N., et al. (2025) [48]	United Kingdom	South Lanarkshire, Scotland	Urban and Rural	Health and social care systems for older adults	Qualitative	Adapted existing framework	CLD	Stakeholder review and feedback, literature comparison, presentation to policy practitioners	Inf pol pro hea str str pla ma dri phe
O'Halloran, S. A., et al. (2025) [49]	Australia	Southwest Victoria	Urban and Rural	Maternal and Newborn Healthcare	Qualitative	Conceptualized the framework, participatory approach stakeholders	CLD	Iterative refinement and participant validation during workshops	Inf pol pro hea str str pla
Paina, L., et al. (2014) [50]	Uganda	Kampala	Urban	Primary health care	Qualitative	Conceptualized the framework, participatory approach stakeholders	CLD	Iterative refinement; triangulation across interviews and documents	Inf pol pro hea str str pla
Pineo, H., et al. (2020) [51]	United States, Australia	San Francisco, Melbourne, Sydney	Urban	Primary health care	Qualitative	Conceptualized the framework, participatory approach stakeholders	CLD	Participatory workshop, cross-validation with interview data, iterative refinement of clds	Ma dri phe Inf pol pro hea str
Qin, R., et al. (2024) [52]	United States, China	New York, Hong Kong, Nanjing	Urban	Public health emergencies	Both Qualitative and Quantitative	Conceptualized the framework, literature review	CLD and SFD	Calibration with actual covid-19 data; comparison with reported cases	Inf pol pro hea str hea pla em pre
Rwashana, A. S., et al. (2009) [53]	Uganda	Mukono	Urban and Rural	Immunization	Qualitative	Adapted existing framework, literature review, participatory approach stakeholders	CLD	Stakeholder feedback, interviews with health workers and mothers	Ma dri phe Inf pol pro hea str
Rwashana, A. S., et al. (2014) [54]	Uganda	Kampala	Urban	Maternal and Newborn Healthcare	Qualitative	Adapted existing framework, literature review	CLD	Stakeholder review (local and international experts)	Inf pol pro hea str hea ana
Semwanga, A. R., et al. (2016) [55]	Uganda	National scope	Urban and Rural	Maternal and Newborn Healthcare	Quantitative	Adapted existing framework, participatory approach stakeholders	CLD and SFD	Stakeholder workshops, spss analysis, scenario testing	Inf pol pro hea str pol eva

Authors	Country of study	Region	Setting (Urban/pre-urban/both)	Healthcare field	Modelling approach	Model building process	Diagram used	Model validation	Ap an mo
Sooka, C. and A. Rwashana-Semwanga (2011) [56]	Uganda	Kampala	Urban	Maternal and Newborn Healthcare	Qualitative	Conceptualized the framework, participatory approach stakeholders	CLD	Stakeholder feedback on descriptive framework, iterative refinement through interviews and discussions	Ma dri phe Inf pol pro hea str
Wu, Q. and Z. Chen (2023) [57]	China	Sanming, Fujian	Urban and Rural	Primary health care	Both Qualitative and Quantitative	Conceptualized the framework	CLD	Comparison with national and provincial data, prescription audits,	Inf pol pro hea str pol eva

SFD - Stock and flow diagram, CLD - Causal loop diagram

Characteristics of the included studies

Countries with several studies included Australia (n = 6, 19%), Uganda (n = 5, 16%), and the United States (n = 4, 13%) (Fig. 3). Fourteen studies (44%) were conducted exclusively in urban areas, while 56% (n = 18) were conducted in heterogeneous areas containing both urban and rural settings.

Figure 3: Spatial distribution of the identified studies (grey = 0 studies).

We summarised the healthcare fields into six broad but interrelated areas (Table 3). MNH accounted for the largest field among the studies, 31% (n = 10), followed by communicable disease control and prevention at 21% (n = 7), which included tuberculosis, cholera, and COVID-19.

Table 3
Multiple classification of healthcare field captured in included studies (n = 32)

Healthcare	N (%)	References
Maternal and newborn healthcare	10 (31%)	[27, 31, 32, 38, 42, 43, 49, 54–56]
Communicable disease control	7 (22%)	[33–36, 40, 45, 53]
Primary health care	6 (19%)	[26, 44, 46, 50, 51, 57]
Healthcare promotion	5 (16%)	[28, 30, 33, 35, 37]
General healthcare system resilience	4 (13%)	[39, 41, 48, 52]
Mental health	2 (6%)	[29, 47]

Studies had multiple healthcare field, and the sum of the percentages is > 100%

There were seven outcomes studied by the ten studies focusing on MNH. We classified these outcomes by domain based on the WHO and UNICEF primary healthcare measurement framework [58] which is designed as a result chain. Health system outputs (access and availability) include maternal health demand and utilisation of maternal healthcare services [56]. Health system inputs and processes (service delivery) outcomes captured the influence of structural barriers on delivery services [38, 43] and payment for performance schemes on maternal and child healthcare services [32]. Quality of care outcomes included prenatal diet quality, poor maternal health outcomes and caesarean section reduction. Finally, health system outcomes (health status) included neonatal mortality (n = 3) [27, 54, 55]. The outcomes explored in the other health fields are presented in the supplementary material (additional file II).

Data source

Diverse data sources were used during model conceptualisation or formulation (Table 4). The majority of studies combined data from sources which were categorised as either primary (94%) or secondary (63%) data. Only 38% used exclusively primary data and 6% solely secondary, while 56% used both sources. Under the primary data sources, stakeholder interviews (24 studies; 75%) and workshops (12 studies; 38%) were the most frequently used, while other group-based techniques, such as focused group discussions (3%) and individual-level, including qualitative cohort studies (3%) and questionnaire surveys (6%), were comparatively less utilised. Observational methods accounted for 9% (3 studies).

Table 4
Data sources used by included studies (n = 32), multiple data sources per study possible

Data Source			N (%)	References
Primary data (n = 30)	Individual-level (n = 24)	Stakeholder interviews	24 (75)	[27],[33],[32],[46],[56],[53],[28],[30],[34],[26],[37],[39],[36],[35],[43],[45],[42],[48],[57],[55],[50],[54],[51],[31]
		Questionnaire survey	2 (6)	[46],[56]
		Qualitative cohort study	1 (3)	[27]
	Group-based (n = 13)	Workshops	12 (38)	[29],[47],[40],[38],[41],[35],[43],[49],[45],[42],[46],[51]
		Focus group discussion	1 (3)	[32]
	Observational (n = 3)	Field observations	3 (9)	[33],[46],[53]
Secondary data (n = 20)	Documents (n = 15)	Government policy reports	7 (22)	[52],[34],[33],[28],[35],[48],[50]
		Journals and published research	5 (16)	[27],[48],[51],[53], [51],[56]
		Health Statistics Yearbook	3 (9)	[44],[57],[52]
		Media articles	2 (6)	[33],[34]
		Organizational reports	2 (6)	[45], [39]
		Government website	1 (3)	[57]
		Health management information reports	1 (3)	[39]
	Health system and administrative data (n = 6)	Center for Disease Prevention and Control (CDC) data	2 (6)	[44],[52]
		Health Management Information System (HMIS) data	1 (3)	[26]
		Historical data from health departments	1 (3)	[38]
		Human Resource Information System (HRIS) data	1 (3)	[26]
		Patient historical data	1 (3)	[56]
		Regional health authority data	1 (3)	[31]
	Population and Survey data (n = 4)	Demographic and Health Survey Data	3 (9)	[27],[56],[55]
		Bureau of Statistics	1 (3)	[55]
		Ministry of Public Health (MoPH) Data	1 (3)	[44]
		National routine surveys	1 (3)	[44]
	Environmental data (n = 1)	Meteorological data	1 (3)	[44]

Studies had multiple data sources, and the sum of the percentages is > 100%

Among the secondary data sources, documents accounted for 65.6% (21 studies) while health and administrative data and population and surveys data contributed about a fifth of the studies, each. Government policy reports (7 studies, 22%) and published research (5 studies, 16%) were the most form of documents.

Modelling approach and simulation

Of the included studies, the qualitative SDM approach was by far the most common (n = 24, 75%). Some studies applied both qualitative and quantitative SDM approaches (n = 6, 19%), while others used only quantitative methods (n = 2, 6%). For those studies that employed quantitative SDM, a simulation was conducted in 9 (26%) studies, whereas in qualitative studies, a simulation was not performed, i.e., 25 (74%) studies.

Model formulation

There were three common approaches used to formulate a SDM including conceptualisation of a new framework (n = 24, 71%), a participatory approach with stakeholders (n = 20, 59%), and adaptation of existing frameworks (n = 10, 29%). However, most studies used these methods in combination (supplementary

material II), with participatory approach involving stakeholders and the conceptualisation of a new framework (n = 13, 16%) being the most common combination.

For the studies that explicitly conceptualised a framework from scratch, they indicated a structured approach to define system boundaries, variables, and relationships. For instance, Ahmad, et al. [27], started with a high-level problem structuring exercise, including conceptualisation of the health-seeking behaviour of pregnant women from pregnancy to delivery, followed by the construction of a schematic map to describe the process. They then constructed a qualitative mapping of causal relationships (the CLD) to portray the processes of pregnant women seeking antenatal care and delivery services from professional providers, as influenced by other factors identified in the literature, and then developed a simulation model (SFD).

Some studies adapted existing frameworks to guide their model development, suggesting efforts to build upon or tailor previously validated models (21%; n = 7). For example, WHO health system building blocks [28], systems thinking principles developed by Meadows & Wright (2008) [29], a six-phase framework informed by a chronic disease prevention framework [30], grounded theory coding, dynamic synthesis methodology [37], thematic approach [53] and a dynamic performance management (DPM) framework [31]. Literature reviews were used as a foundational step in 21% (n = 7) of the studies, while expert involvement was reported in only 12% (n = 4).

Diagrams and Pathways/Mechanisms

To represent the interaction between components within the SDMs, a CLD was employed in most of the studies (n = 26, 81%), whereas both CLD and SFDs were used in the remaining studies (n = 6, 19%). The six studies that applied both CLD and SFDs employed both qualitative and quantitative modelling approaches. The pathways between the interacting components were represented by feedback loops (reinforcing and balancing) for the qualitative modelling approach, and in studies where both qualitative and quantitative approaches were used, both feedback loops (reinforcing and balancing) and stocks and flows represented the pathways. Polarity (+/-) showed the direction of influence, and the arrows indicated causal relationships.

Validation/testing

A range of validation and testing methods were employed to assess the credibility and robustness of the models in all 32 studies. Internal validation through iterative coding and consensus among researchers was used, alongside expert validation via workshops, interviews, and email feedback (n = 6). Seven studies applied triangulation techniques, combining interviews, documents, observations, and stakeholder feedback. Stakeholder validation was conducted through interviews, workshops, and participatory forums (n = 13). Two studies incorporated formal testing methods such as boundary-adequacy, extreme condition, and dimensional-consistency tests, unit consistency and structural validity tests, and behavioural replication. Quantitative validation was performed in four studies using historical data and calibration with actual datasets.

Modelling tools

In this review, we focused on the software applications that were used for system dynamic modelling among all software tools used across the studies. Vensim was the most frequently used, accounting for 56% (n = 18) of the studies. STELLA Architect and STICKE followed, each contributing to 9% (n = 3) of the studies. Less commonly used tools included KUMU and Visual Anthropac, each representing 3% (n = 1). Notably, 22% (n = 7) of the studies did not specify the software they used.

Application, use and limitations of the model

The use and purpose of the models developed in the identified studies varied, with a strong emphasis on informing policies to promote health system strengthening (n = 25, 78%). Strategic planning was the second most common application (n = 11, 34%), often combined with policy-related goals to guide future interventions and resource allocation. Mapping drivers for phenomena was also a key use (n = 10, 31%). Other notable applications included policy evaluation (n = 5, 16%), emergency preparedness, and understanding the drivers for promotion of healthy urban planning(each n = 4, 12.5%).

Model limitations were identified in the included studies; most models were developed using qualitative methods, lacked quantitative simulation or predictive capabilities (n = 6). Stakeholder participation was restricted to experts, with minimal or no involvement from frontline workers and beneficiaries such as healthcare users (n = 7). Some models relied on small or region-specific datasets (n = 7), assumed static populations, or homogeneity within socioeconomic subgroups. Additionally, key system elements such as governance structures and intervention mechanisms were omitted in some studies (n = 5).

Model conceptualization – subset of studies on maternal and newborn health (n = 10)

In conceptualising the CLD, we used the key elements summarised in Table 6 from the identified studies, which focused on MNH, that define the structure and behaviour of the system. The key elements were grouped into four levels (national, facility, local area, and community), and subgroups were created within each level, as shown in Table 5. In each subgroup, we identified the key elements and discontinuities, then defined the causal relationships between them based on the literature. Modifications were made through discussion between co-authors, followed by the identification of feedback loops that influence key outcomes over time.

Table 5
The key elements and discontinuities

Level	Sub-groups	Key elements	Discontinuities
National	Policies	National subsidies	Policy resistance, Policy changes, Policy gaps
	Health governance	Leadership, Government action, Supervision	Poor leadership, Non-financial incentives, Advocacy initiatives
Facility	Healthcare services	Delivery services, ANC services, Postnatal care, Facility reporting, Health worker availability, Training, Workload, Referral systems, Drug/equipment availability, NGO support	Delays in drug supply, Staffing shortages, Equipment maintenance issues, Patient drop-out, Pandemic disruptions, Improved supplies, Free sustainable supplies
	Quality of care within facility	Service care provider types, Quality of care, Staff competence, Staff support, Health worker motivation	Structural barriers, Fragmented care, Clinician bias, Time constraints, Ineffective referral and transport systems
Local area	Economic factors	Education and Income, Knowledge, Literacy, Personal and family circumstances, Affordability,	Socioeconomic barriers,
	Environmental/climate factors	Food availability and access, Weather	
	Trust and communication	Information	Healthcare distrust, Media effect, Misinformation, Mobilisation, Awareness,
Community	Social	family support, social mobility, Social network influence factors, Personal and norms, politics, Family counselling	Abusive relationship
	Cultural Influences	Community norms, Myths	

We further categorised these elements into six subsystems, then organised a simplified high level snapshot of the relationship between subsystem to represent dynamic interactions as illustrated in Fig. 3, which visualises the subsystems and their interconnections. These include leadership and governance, infrastructure and supplies, human resources, maternal and neonatal service delivery, women seeking care, and health outcomes. Leadership and governance, together with infrastructure and human resources, form the foundational components, which are considered as structural determinants by WHO, that directly facilitate effective service delivery, representing macro (broader structural, societal, and policy environment) and meso levels (organizations, communities, social cultural and economic aspects and groups).

Women's care-seeking behaviour, which represents the micro level (individuals and their immediate interactions), interacts with MNH service delivery to determine utilisation patterns, while maternal and newborn health outcomes represent the ultimate measure of system performance. The directional arrows indicate causal relationships among these components, highlighting their interconnected nature.

At the macro level, leadership and governance, policy changes, and resource allocation shape the strategic priorities, funding flows, and accountability structures that guide maternal and neonatal services. These influences do not affect service delivery directly; instead, they operate through feedback loops that interact with meso-level subsystems, such as leadership and team building in the organisational capacity, workforce distribution, and service coordination. Over time, reinforcing feedback (R1 and R2) within these loops can amplify initial changes, meaning that policy decisions and governance practices may lead to cumulative improvements or deteriorations in service delivery, rather than immediate or linear effects. Policy resistance and gaps emerge as critical discontinuities, weakening system responsiveness to manage new crises and health system strengthening activities.

At the meso level within the health facility, staffing shortages, workload, and equipment issues interact with health worker motivation and training, as well as other elements shaping the quality of care. Delays in drug supply, such as those affected by pandemic related disruptions further strain service delivery. At the micro level, socio-cultural determinants such as religion, literacy and education level, household wealth, and family influence affect women's care-seeking behaviour. These dynamics collectively impact maternal and neonatal service delivery and health outcomes.

Discussion

This scoping review synthesised evidence on SDM methodological approaches in urban healthcare, focusing on the key elements and discontinuities influencing MNH service utilization and provision, and their interactions within a conceptual model of urban MNH system. We identified 32 studies, most of which were from high income settings, indicating limited evidence from low- and middle-income contexts. There has been a notable increase in the application of SDM in healthcare in the past 10 years. In the sections that follow, we discuss the applications and methods used in SDM, followed by the elements and discontinuities affecting MNH in urban areas.

Methodological approaches in SDM

Three in every four studies employed a qualitative SDM approach. As Wolstenholme [59] noted, qualitative SDM approaches are valuable for conceptualising complex systems and fostering stakeholder engagement, a pattern reflected in the studies reviewed. However, the selection of CLDs and SDMs as a methodology is guided by how the research question is intended to be investigated. CLDs are useful for conceptualising system structure, feedback, and context, particularly in exploratory phases. However, when the aim is to examine system behaviour over time or to test policy interventions, qualitative approaches alone are insufficient. Without quantification, models cannot reliably infer system behaviour or test policy interventions, limiting their utility for

decision-making [60]. Healthcare systems exhibit nonlinear feedback, which qualitative diagrams alone cannot capture. Additionally, while qualitative evidence describes the contexts, policy decisions solely based on such evidence may remain acceptable but lack testable models or quantitative analysis that confirm their feasibility in the real world [61]. In progressing to a quantitative SDM, policy options can be tested 'in the lab' to provide insight into intended (and unexpected) policy impact before real world implementation. [62] [63].

However, the predominance of qualitative SDM should not be interpreted as methodological sufficiency or a limitation of the approach, as it plays a fundamental role in developing a shared understanding of complex systems and engaging research teams and stakeholders. Rather, this pattern highlights the added value of using both qualitative and quantitative SD methodologies in contexts where scenario testing and assessment of policy impacts on outcomes are required, which were employed in only a tenth of the studies reviewed.

In the formulation of SDM, we found that most studies conceptualised a framework from scratch and combined it with a participatory approach involving stakeholders. In contrast, a relatively small proportion adapted existing frameworks within health systems research. This suggests that researchers often prefer to build models grounded in local problem contexts rather than relying on pre-existing ones, a tendency that aligns with the modelling literature emphasising the importance of contextual fit and stakeholder-based understanding in SDM [64] [65]. However, frequent development of entirely new conceptual frameworks may undermine methodological coherence across studies. For instance, Sterman [18] and Lane [66] emphasize that insufficient use of established frameworks contributes to fragmentation and hinders cumulative model-building. Similarly, George et al. [67] argues that the limited adaptation of validated frameworks restricts opportunities for cross-study comparability and learning. Thus, while the preference for context-specific model formulation offers clear advantages, it also presents challenges for reproducibility and drawing generalisable recommendations for other settings that remain widely recognised in SDM research [50, 68–70].

MNH as a key application area and gaps in outcome measurement

MNH was the most common healthcare field in the reviewed SDM studies, accounting for one-third of the articles. These studies were conducted across settings of all income-levels, reflecting the universal relevance of MNH challenges. The predominance reflects the persistent burden of maternal and newborn mortality and the complex, multi-factorial nature of MNH pathways, both of which makes SDM particularly suitable for MNH. This aligns with Kruk et al. [71], who highlight that MNH outcomes depend on dynamic interactions among behavioural, social, clinical, and health system factors, making MNH an area where SDM is especially valuable for capturing feedback loops and nonlinear relationships. Furthermore, according to Chmielewska et al. [72], maternal and newborn services were among the most disrupted during the COVID-19 pandemic, heightening global attention on their vulnerability and contributing to increased interest in applying SDM. In addition, Campbell et al. [73] state that global policy priorities such as the Sustainable Development Goals and earlier Millennium Development Goals have historically directed funding and research attention toward MNH, contributing to a larger evidence base and modelling interest compared to areas such as mental health. However, currently the trends are reversing and funding is shifting away from sexual and reproductive health research and global health in general [74]. Therefore, SDM could have a role in predictions and strategising to overcome such shocks.

These findings highlight a range of outcomes examined in studies focused on MNH, which paid limited attention to end-point health outcomes such as neonatal mortality. While these other outcomes from the supply and demand side provided valuable insights into MNH system functioning, they remain proxy measures and do not fully capture whether care ultimately saves lives. Donabedian's model [75] emphasises that outcome measures (i.e., neonatal or maternal mortality) are the ultimate test of a health system's effectiveness, beyond structure and process. Further, implementation research and health system strengthening reviews likewise emphasise that many interventions cluster around improving process measures, quality improvement methodologies, or system readiness, but not enough work ties these to downstream mortality or morbidity, as emphasised by Mianda et al. [76]. Given this gap, it would be particularly valuable for future research to place greater emphasis on final health outcomes, such as neonatal and maternal mortality, stillbirth, or severe morbidity, to ensure that improvements in the MNH systems translate into lives saved.

Modelling tools

In the reviewed studies, the choice of modelling tools reflects both historical preferences and evolving technological capabilities. Vensim, used in over half of the studies, remains the major software for system dynamics modelling. Its popularity can be attributed to its robust functionality for CLDs, stock-and-flow modelling, and simulation, as well as its accessibility for academic and professional users [77]. Vensim's widespread adoption also suggests a strong alignment with traditional SD practices and its ability to handle complex feedback structures efficiently [78, 79]. STELLA Architect and STICKE represented alternative platforms that emphasize user-friendly interfaces and visual modelling capabilities. STELLA, for instance, is often preferred in educational and participatory settings due to its intuitive design, which facilitates stakeholder engagement and comprehension of dynamic models [80, 81]. Similarly, STICKE supports collaborative modelling, making it suitable for group model building processes [82].

Urban MNH CLD - Key elements, discontinuities

The CLD conceptualised in this paper highlighted several elements that are particularly pronounced in urban settings and have important implications for MNH. High workloads and chronic staffing shortages, also observed in rural facilities, are intensified in urban settings by the coexistence of public, faith-based, and numerous low-quality private providers, often competing for qualified staff and contributing to variability in care quality, an issue widely documented in rapidly urbanizing countries as highlighted by UrbanBirth Collective [5]. Additionally, Urban-specific governance and referral challenges further complicate service delivery: traffic congestion, delayed ambulance response, and weak coordination across heterogeneous providers significantly hinder timely obstetric referrals in urban environments, as shown by Panciera et al. [83], where transportation bottlenecks significantly hinder emergency care at the time of childbirth. Supply-side constraints such as drug stock-outs, equipment shortages, and fragmented referral pathways are also common in large cities with complex public–private service provision landscapes, which is highlighted by Sivaramakrishnan [84] and Kruk et al. [71]. Social dynamics such as healthcare distrust, misreported risks and influence of mobile populations further complicate maternal care-seeking and continuity of care in urban contexts [85, 86]. Moreover, environmental and socioeconomic pressures such as poor living conditions in informal settlements and pronounced income inequalities

exacerbate maternal and newborn health risks despite geographic proximity to health facilities [87]. Together, these factors underscore the multifaceted nature of urban maternal healthcare and reinforce calls for system-based interventions that address both structural and behavioural drivers unique to urban health systems [88].

The MNH SDMs developed in the reviewed studies reveal the complexity of MNH systems, characterised by multiple interacting subsystems and discontinuities that affect service delivery, health-seeking behaviours, and outcomes. The identified key elements span across national, facility, local, and community levels, reflecting the multi-layered nature of health systems [89, 90]. At the national level (macro level), policies and governance structures including subsidies, leadership, and government action, form the backbone of system functioning [91]. However, discontinuities like policy resistance, frequent policy changes, and gaps in implementation weaken the system's ability to sustain improvements; poor leadership and limited accountability exacerbate these challenges, highlighting the need for stronger governance and adaptive policy frameworks [92, 93].

At the facility level, healthcare services and quality of care are central components but are often disrupted by discontinuities such as drug supply delays, staffing shortages, equipment maintenance issues, and pandemic-related disruptions [5, 94, 95]. Quality of care is compromised by structural inequalities and institutional barriers, misreported risks, which collectively erode trust and equity in urban maternal health services [96]. The local area level (macro) elements, such as education level, income, and food availability [97] interact with discontinuities such as healthcare distrust, misinformation, and affordability barriers. These interactions limit access and utilisation of services, underscoring the importance of community engagement and targeted health communication strategies [98]. At the community level, social and cultural influences such as family support, social norms, and community beliefs play a pivotal role in shaping the health-seeking behaviour of women by either reinforcing positive practices or perpetuating harmful norms that affect the MNH system's performance [99].

Overall, the interplay between these elements and discontinuities illustrates the dynamic complexity of MNH systems. Addressing these challenges requires multi-level interventions that strengthen governance, improve facility-level resources and quality, and tackle socio-cultural barriers through participatory approaches. The formulated CLD, provides a valuable lens for identifying leverage points and anticipating unintended consequences, enabling a more resilient and equitable urban MNH system. Future studies can rely on it as a starting point, but it will require further adaptation based on context.

Policy and methodological recommendations

To strengthen MNH interventions and systems in urban settings through SDM, we recommend the following: First, adopt SDM approaches that integrate qualitative stakeholder insights with quantitative simulation to enable scenario testing and anticipated system-wide impacts. Second, we encourage the use of validated and context-specific SDM frameworks to enhance robustness and targeted application. Third, SDM should be applied across policy design, implementation, and evaluation to simulate interdependent components of urban MNH systems, thereby enabling policymakers to anticipate operational barriers, test communication and engagement strategies, and link implementation processes to health outcomes over time. Finally, a capacity-building policy should support regular training for policymakers and health managers in SDM and systems thinking, as their mental models are a critical component of SDM to embed dynamic modelling into routine planning and decision-making.

Strengths and limitations

This scoping review provides an evidence base on how SDM has been applied to investigate research questions related to urban healthcare with a focus on MNH systems, offering a comprehensive synthesis of existing studies in accordance with PRISMA-ScR guidelines to ensure transparency and methodological rigour. To our knowledge, this is the first review to synthesise, in depth, the methodological approaches used to conceptualise and model the complex, interrelated key elements of MNH within urban health systems. Nonetheless, limitations should be acknowledged. First, although the scoping review identified studies across continents, the emphasis on English and French languages may have introduced a language bias, limiting other languages. Second, the inclusion of grey literature could have provided for a greater range of insights on SDM. Finally, the studies reviewed were conducted in urban settings, so studies focusing on rural contexts or comparing SDM methods applied in urban versus rural areas would have revealed important differences in how SDM is implemented across diverse healthcare environments.

Conclusion

While SDM is increasingly recognised as a powerful tool for understanding complexities in urban healthcare, further methodological consolidation, stronger use of existing frameworks, and greater emphasis on final health outcomes are essential for advancing its policy relevance. Integrating hybrid SDM approaches, strengthening urban health system infrastructure, and embedding systems thinking into policymaking can enhance the design and evaluation of interventions aimed at reducing maternal and neonatal mortality. Ultimately, by harnessing the full potential of SDM, policymakers and researchers can develop more effective, context-sensitive, and sustainable strategies that address the unique needs of urban populations and improve MNH outcomes worldwide.

Declarations

Author's contributions

Rehema K. Ouko: Conceptualization, Literature search, Screening, Data curation, Formal analysis, Writing - original draft. **Lenka Beňová**: Conceptualization, Supervision, Methodology, Writing - review & editing, Funding acquisition. **Peter M Macharia**: Conceptualization, Supervision, Methodology, Screening, Writing - review & editing, Funding acquisition. **Aline Semaan**: Screening, Writing - review & editing. **Negin Yahaghi**: Screening, Writing - review & editing. **Rachel Cassidy**: Supervision, Methodology, Writing - review & editing. **Josefien van Olmen**: Supervision, Methodology, Writing - review & editing. **Fassou Mathias Grovogui:** Investigation , **Nafissatou Dioubate:** Investigation.

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Availability of data and materials

The datasets are included within the article and its additional files.

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Competing interests

The authors declare no competing interests.

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Figures

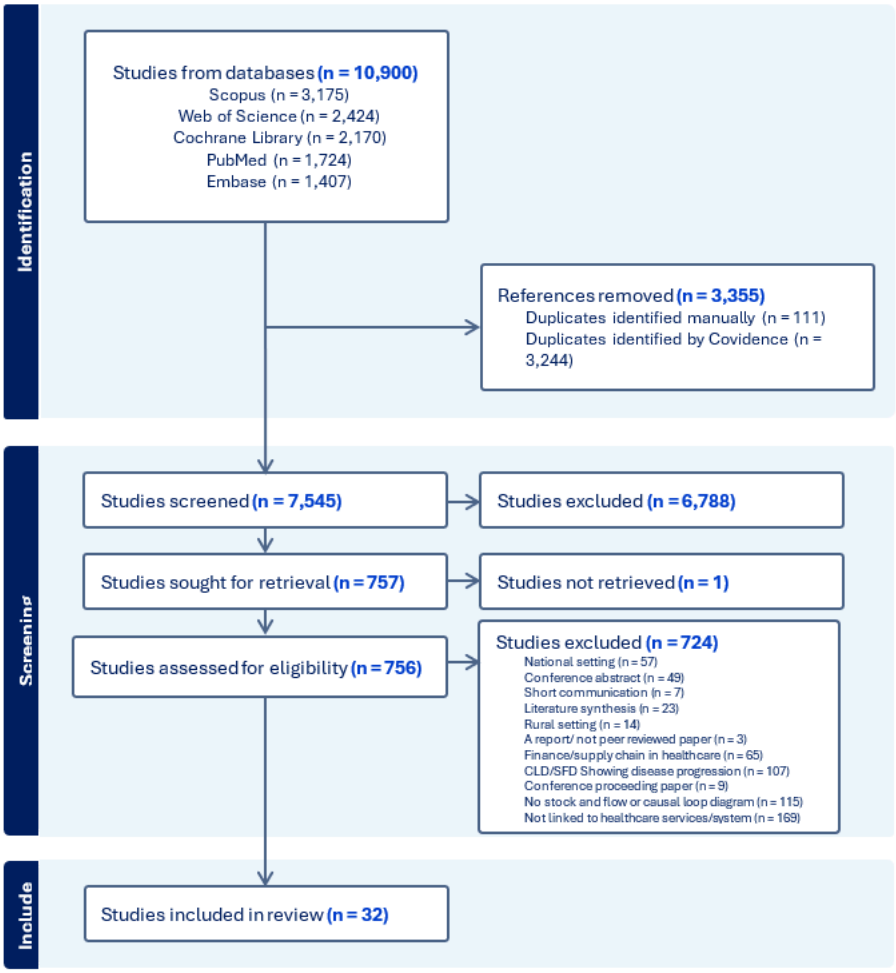


Figure 1

PRISMA [23] Flow Diagram showing the search results and study inclusion process at each stage of the scoping review

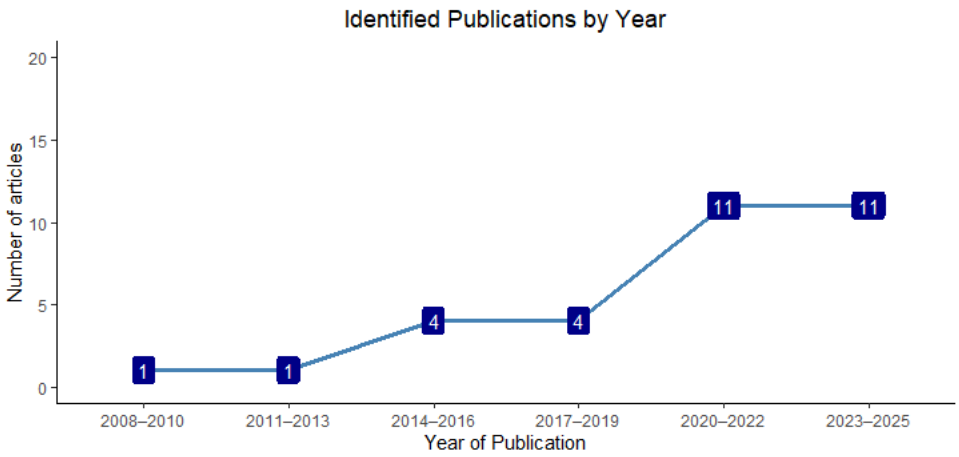


Figure 2

Number of identified articles by year of publication

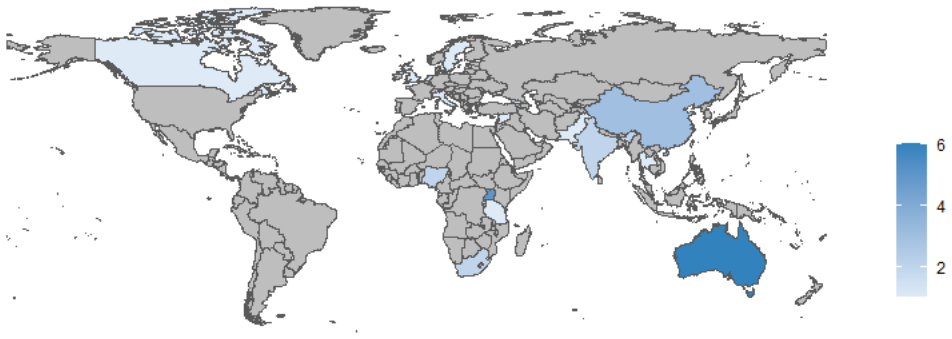


Figure 3

Spatial distribution of the identified studies (grey = 0 studies).

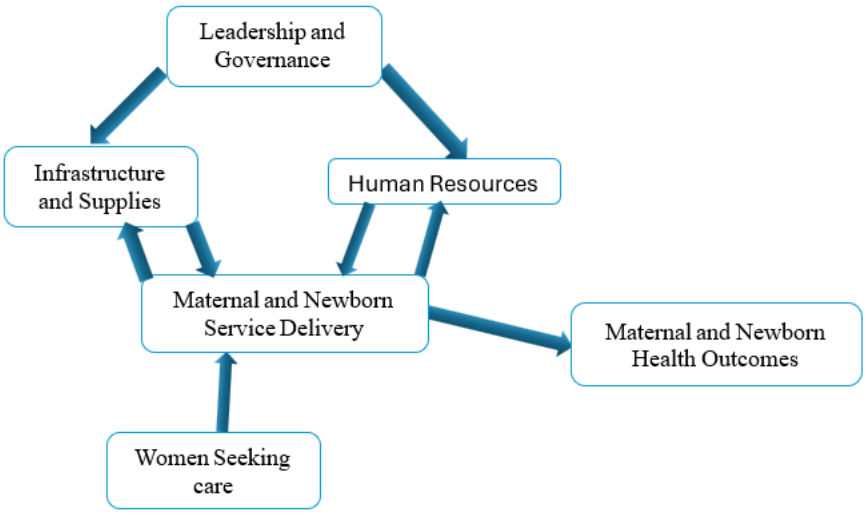


Figure 4

Figure 3: A high level snapshot of the relationship between subsystems that feature in the CLD representing the urban maternal and newborn healthcare system.

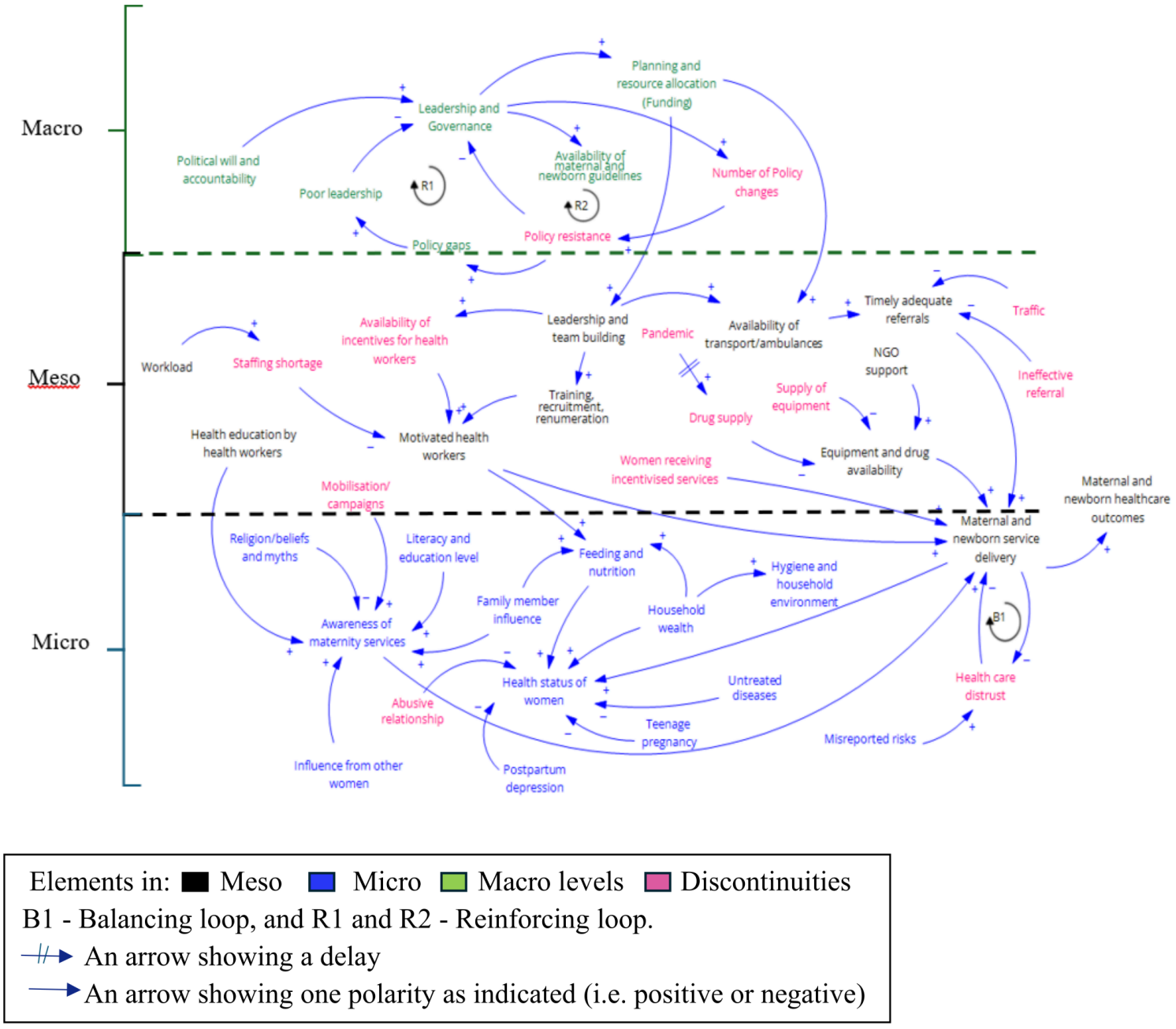


Figure 5

Figure 4: A Causal loop diagram describing facilitators and discontinuities to delivery and utilisation of urban MNH services, illustrating the complex interconnections among the elements within the subsystems and maternal and newborn health outcomes.

Supplementary Files

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