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Enhancing antenatal care through SMS-Based interventions in developing countries: A systematic review of applications and their effectiveness

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Abstract

Background: Pregnant women in Mali and other similar settings face a challenge due to limited access to comprehensive health information and services. Mobile health (mHealth) interventions, particularly SMS-based ones, have shown promise in addressing maternal health challenges in low- and middle-income countries (LMICs).

Objective: This review aims to provide an overview of existing SMS-based antenatal care (ANC) applications and assess their effectiveness in improving maternal and child health outcomes.

Methods: A systematic literature review based on the updated PRISMA 2020 guide was conducted, including 12 studies from a dataset of 776 published between 2014 and 2024 retrieved from electronic databases such as PubMed, Scopus, Web of Science, The Cochrane Library, Association for Information Systems eLibrary, Direct science and Google Scholar. The Version 2 of the Cochrane risk-of-bias tool for randomised trials (RoB 2), the Risk Of Bias In Non-randomised Studies - of Interventions (ROBINS-I) and the Checklist for Reporting the Development and Evaluation of Complex Interventions in Healthcare (CReDECI) were used depending on the study design types to assess the risk of bias in each included paper.

Results: The review identified a range of SMS-based interventions that differed in target audience, message frequency (weekly, pregnancy stage oriented), and content (reminders, educational, danger signs). Implementation tools varied from essential SMS gateways to custom applications and third-party platforms, with some interventions combining these approaches. Across the reviewed studies, SMS interventions positively impacted ANC attendance, maternal health knowledge and behaviours. However, the degree of effectiveness varied based on the content of messages, frequency of messaging, and the implementation approach.

Conclusion: SMS-based interventions have a significant potential to enhance ANC in LMICs by providing tailored health information and promoting healthy behaviours. Further research

should focus on refining or replicating these interventions and exploring their long-term impact on maternal and child health outcomes.
Keywords: Antenatal Care, ANC, mHealth, SMS-Based intervention, LMICs

Strengths and limitations of this study

- This review utilised the PRISMA 2020 guidelines, ensuring a thorough and standardised approach to conducting the systematic review hence enhancing the transparency and reproducibility of the research process
- The risk of bias in included studies was meticulously assessed using three robust tools: the RoB 2, ROBINS-I, and the CReDECI
- This review assessed the effectiveness of SMS-based interventions for improving antenatal care and maternal health in LMICs, addressing a critical gap in the literature.
- A notable limitation is that only one reviewer (the corresponding author) assessed the included papers

1 Introduction

The lack of comprehensive health information and services for pregnant women is a significant challenge to improving maternal and child health in Mali and similar settings. The literature reports that knowledge of the place of consultation, treatment costs, pregnancy complications and the place of antenatal care treatment significantly influence maternal mortality (Azuh et al., 2017). Additionally, regarding services, births attended by skilled health personnel correlate with maternal mortality in sub-Saharan Africa (Buor & Bream, 2004). Poor antenatal and maternal health awareness among pregnant women contributes to inadequate health behaviours and care seeking, causing avoidable morbidity and mortality.

Antenatal care (ANC) is a critical component of maternal healthcare, aimed at monitoring and enhancing health outcomes for pregnant women and their unborn children. Regular ANC visits enable healthcare providers to detect and manage potential health problems, educate women about pregnancy and childbirth, and advocate for healthy behaviours that benefit both the mother and the child (Al-Ateeq & Al-Rusaiess, 2015; Meskele et al., 2023; Tola et al., 2021). Despite the global recognition of ANC's importance, significant challenges persist in ensuring comprehensive care for all pregnant women, particularly in low and middle-income countries (LMICs). Studies have shown that maternal education, household income, and cultural beliefs significantly impact the utilisation of antenatal care services, with disparities in access and use across different socioeconomic and demographic groups (Simkhada et al., 2008; Tola et al., 2021). Addressing these challenges requires targeted interventions to improve access, awareness, and affordability of ANC services for pregnant women in these regions.

The swift growth of mobile technology has led to innovative ways to increase healthcare access and engage patients. SMS-based systems have become vital in closing the information gap and boosting engagement with antenatal care services. Indeed, these applications offer a platform for delivering timely, relevant information directly to the mobile phones of pregnant women, thus increasing awareness about the importance of ANC, reminding women of their upcoming appointments, and providing crucial health-related guidance (Lund, Nielsen, et al., 2014; Masoi & Kibusi, 2019; Nuhu et al., 2023; Ronen et al., 2021; Wagnew et al., 2018). Studies have

demonstrated the potential of mHealth (mobile health) interventions to monitor prenatal care among pregnant women in LMICs (Mishra et al., 2023) and evaluated the effectiveness of SMS on focused ANC visits and skilled birth attendance in such settings (Wagnew et al., 2018).

Incorporating SMS-based interventions into maternal healthcare is part of a more significant trend towards utilising mHealth solutions to enhance healthcare delivery and patient outcomes. This literature review examines the existence and scope of interventions using SMS-based applications specifically tailored to improve the dissemination of ANC information and the attendance of pregnant women at ANC visits in developing countries. Additionally, it assesses the evidence concerning the effectiveness of these interventions in fostering maternal and neonatal health outcomes. By exploring the impact of SMS-based applications on metrics such as antenatal care visit attendance and skilled birth attendance, this review aims to illuminate the potential of digital interventions to complement traditional ANC services and contribute to the reduction of maternal and neonatal morbidity and mortality, thereby supporting public health goals (Coleman et al., 2017), and with the ultimate aim of contributing to the broader global health new narrative as suggested by Malqvist and Powell (2022) i.e., health, sustainability and transformation. The rest of the paper is organised as follows. In the second section, the methodology used is accurately detailed by describing the research question, data sources for the study, the search strategy employed, the selection criteria of studies included in the dataset, and the data extraction process. We also present in that section the tools used for the analysis of the dataset, the data characteristics, and the risk of bias assessment process. In the third section, the results are presented and discussed. Finally, we conclude the paper in section four.

2 Methodology

A systematic approach was employed to identify and evaluate significant findings concerning using SMS-based interventions to improve ANC in developing countries, as documented in peer-reviewed French and English online journals over the past decade. To ensure a thorough and effective review process, we followed the updated guidelines outlined in the 2020 edition of Preferred Reporting Items for Systematic reviews and Meta-Analyses by Page et al (2021), which guided this study. The PRISMA 2020 Abstracts and Checklist items can be accessed from the appendix of this paper.

2.1 Research questions

In this study, our objectives are to address the following research questions:

RQ1: what SMS-based applications are available to enhance antenatal care information and attendance among pregnant women in low and middle-income countries?

RQ2: what evidence is available on the effectiveness of these SMS-based applications in low and middle-income countries?

2.2 Data sources

The search included the following electronic databases or search engines: PubMed, Scopus, Web of Science, The Cochrane Library, Association for Information Systems eLibrary (AISeL), Direct Science and Google Scholar. The search was extensively conducted in March 2024.

2.3 Search strategy

The formulated research questions guided the construction of search strings, leading to their combination through logical connectors. The resulting string was [("SMS-based applications" OR "text messaging" OR "mobile health" OR "mHealth") AND ("antenatal care" OR "prenatal care" OR "pregnancy care" OR "ANC") AND ("developing countries" OR "low-income countries" OR "resource-limited settings")]. This process was adapted according to the specific requirements of each electronic database accessed. Science Direct, for example, does not accept more than eight logical connectors in one search. The author translated the search string into French by combining the words and expressions used for the English search. The resulting string was ("applications basées sur SMS" OU "messagerie texte" OU "santé mobile" OU "mSanté") ET ("soins prénatals" OU "soins anténataux" OU "soins pendant la grossesse" OU "CPN") ET ("pays en développement" OU "pays à faible revenu" OU "contextes à ressources limitées"). The process used for searching and selecting different publications is summarised as a Diagram Flow and presented in Fig. 1. The flow diagram of the search made with the R-developed online tool by Haddaway et al. (2022). eTable 1 in the supplementary files summarises the detailed results per databases and particular search strategies.

2.4 Selection criteria

Initially, 776 publications were found, as detailed in Table 3. Additional inclusion and exclusion criteria were applied to sift through the initial findings to pinpoint the studies pertinent to our goals. Consequently, these publications underwent a rigorous screening process based on the inclusion and exclusion criteria. These criteria were defined to ensure the relevance and quality of the data analysed. The study design criteria included randomised controlled trials (RCTs), quasi-experimental, observational, and qualitative studies that provided data on the implementation, usage, and outcomes of SMS-based ANC interventions. Excluded were editorials, reviews, opinion pieces, and studies lacking primary data or clear outcomes related to ANC and SMS-based interventions.

The population criteria focused on studies involving pregnant women in LMICs, encompassing women of all ages, ethnicities, and stages of pregnancy. For the intervention criteria, the studies needed to focus on SMS-based systems designed to improve ANC information and attendance. This included interventions promoting health education, appointment reminders, health monitoring, and support through text messaging. Studies not specifically using SMS-based communication as a primary method for delivering antenatal care information or support were excluded.

The comparator criteria allowed for studies with or without a control group. For those with a control group, the comparison could be standard care, no intervention, or other digital health interventions not using SMS. Studies, where the control group was subjected to interventions primarily based on SMS technology or those that did not clearly describe the comparator, were excluded. Regarding outcomes, the included studies needed to measure outcomes related to ANC, such as improvements in attendance, enhanced knowledge of antenatal health, improved pregnancy outcomes, and user satisfaction with the SMS service. Studies that did not report specific outcomes related to ANC were excluded. Additionally, only studies published within

the last ten years, from 2014, were included. Finally, the language criteria specified that the content needed to be written in English or French, with content not written in these languages being excluded.

In the subsequent phase, the process involved verifying the presence of duplicate papers, given that multiple databases were used for the search. This resulted in identifying and removing 11 duplicate documents from the dataset. Full texts of papers were then retrieved and checked. Following this meticulous selection phase, a final count of 12 papers was deemed appropriate and suitable for the review (see Fig. 1).

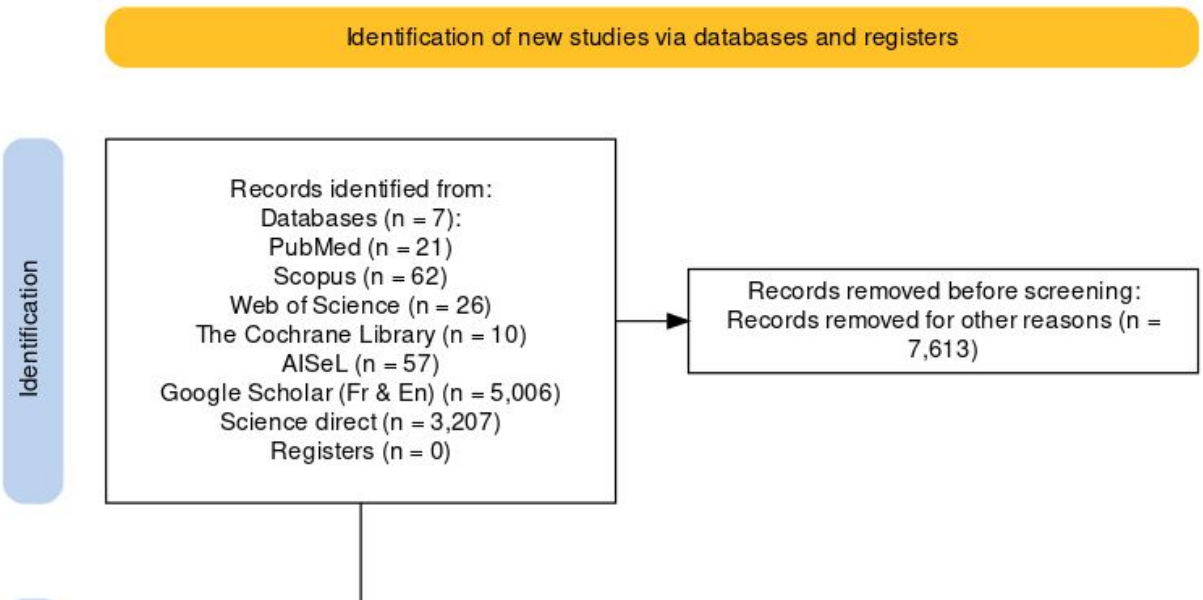

Figure 1 Flow Diagram of the search.

2.5 Data extraction

After completing the selection process, we manually extracted information from the chosen papers. The study identification items extracted included the author names, title of the paper, journal of publication, year of publication, study design type, and the country where the study was conducted. Details regarding study participants were also extracted, including an accurate description of the population, sample size, and the primary inclusion and exclusion criteria. Information on the intervention details extracted includes a general description and purpose of the SMS-based application as presented in the paper, the content of the messages, the frequency of message sending, the resources and tools employed for the implementation, and the duration of the intervention. Additionally, control or comparator interventions were retrieved as reported, if applicable. The reported outcomes (primary and secondary) were extracted accordingly. Regarding the results, key findings related to the indicated outcomes, statistical significance where applicable, and any reported limitations were also extracted. The complete data extraction form is provided in the supplementary eTable 3.

2.6 Tools and analysis

The data set was managed using the open-source desktop-based application Mendeley version 1.19.8. Moreover, the items extracted were stored and used to make descriptive statistics using JabRef (version 5.13), Microsoft 365 Excel app (version 2403) and IBM SPSS Statistics 20.

2.7 Data characteristics

A bibliometric overview of the selected papers is described in Table 1. Each paper was assigned a numerical identifier and categorised in Table 1 according to the year of publication, from oldest to most recent, and by source.

Table 1 Bibliometric overview

ID	Author(s)	Title	Journal/Conf	Country (region)	Year	Source
01	Lund et al	Mobile Phone Intervention Reduces Perinatal Mortality in Zanzibar: Secondary Outcomes of a Cluster Randomized Controlled Trial	JMIR mhealth and uhealth	Tanzania (Zanzibar)	2014	
02	Masoi & Kibusi	Improving pregnant women's knowledge on danger signs and birth preparedness practices using an interactive mobile messaging alert system in Dodoma region, Tanzania: a controlled quasi-experimental study	Reproductive Health	Tanzania (Dodoma)	2019	
03	Nuhu et al	Impact of mobile health on maternal and child health service utilization and continuum of care in Northern Ghana	Scientific Reports	Ghana	2023	PubMed

04	Alhaidari et al	Feasibility and acceptability of text messaging to support antenatal healthcare in Iraqi pregnant women: A pilot study.	Journal of Perinatal Medicine	Iraq	2018	Scopus
05	Ronen et al	Evaluation of a two-way SMS messaging strategy to reduce neonatal mortality: rationale, design and methods of the Mobile WACh NEO randomised controlled trial in Kenya.	BMJ open	Kenya	2021	AISeL
06	Batool et al	Maternal complications: Nuances in mobile interventions for maternal health in urban Pakistan	Proceedings of the Ninth International Conference on Information and Communication Technologies and Development	Pakistan	2017	Google Scholar
07	Atnafu et al	The role of mHealth intervention on maternal and child health service delivery: findings from a randomized controlled field trial in rural Ethiopia	mHealth	Ethiopia	2017	
08	Omole et al	The effect of mobile phone short message service on maternal health in south-west Nigeria	The International Journal of Health Planning and Management	Nigeria	2018	
09	Thompson et al	Connecting mothers to care: Effectiveness and scale-up of an mHealth program in Timor-Leste.	Journal of Global Health	Timor-Leste	2019	
10	Muhoza et al	A mobile-based technology to improve male involvement in antenatal care.	Kabale University Interdisciplinary Research Journal	Uganda	2022	

11	Oliveira-Ciabati et al	SISPRENACEL - MHealth tool to empower PRENACEL strategy.	Procedia Computer Science	Brazil	2017	
12	Kawakatsu et al	Cost-effectiveness of SMS appointment reminders in increasing vaccination uptake in Lagos, Nigeria: A multi-centered randomised controlled trial	Vaccine	Nigeria	2020	Science Direct

2.8 Risk of Bias Assessment

In this study, the dataset comprised 12 scholarly articles. Each article was evaluated for potential bias, with the assessment criteria varying according to the study design employed. To conduct this assessment, three distinct tools were utilised: Version 2 of the Cochrane risk-of-bias tool for randomised trials (RoB 2) tool (J. A. C. Sterne et al., 2019) was applied to eight studies, the Risk Of Bias In Non-randomised Studies - of Interventions (ROBINS-I) tool (J. A. Sterne et al., 2016) to three studies, and the Checklist for Reporting the Development and Evaluation of Complex Interventions in Healthcare (Craig et al., 2008) was conveniently used for one study. Visual representations of the assessments, including traffic light plots (see eFig. 1 and 2) and summary plots (see eFig. 3 and 4), were created for the two groups (RoB 2 and ROBINS-I). Refer to eFigure 5 for the assessment of the study against the checklist. These plots were generated utilising the Risk Of Bias VISualisation (ROBVIS) tool (McGuinness & Higgins, 2020). The overall risk assessment for the papers was categorised as 'some concerns'. Consequently, we did not exclude any of the documents included due to the absence of many significant high/critical issues with individual papers.

3 Results and discussion

3.1 SMS App Inventory (RQ1)

3.1.1 Overview of apps

The dataset consisted of a total of 12 applications. These ranged from basic, one-way SMS-sending apps to more complex, bidirectional communication platforms that connected pregnant women with healthcare providers throughout and sometimes beyond the pregnancy period. Table 2 below provides an overview of the SMS-based applications identified in the literature review, offering a snapshot of their key features and implementation contexts. The table includes details on each app's target population, the key features, and the study design employed to evaluate its effectiveness. App names are given where the authors gave specific names to their developed apps.

Table 2 Overview of apps

App name	Country (region)	Target population	Key features	Study design
The Wired Mothers	Tanzania (Zanzibar)	Pregnant women attending antenatal care at 24 primary health care facilities across six districts on the island of Unguja	• Unidirectional text messaging • a mobile phone voucher system for two-way communication between pregnant women and their primary health care providers.	Pragmatic, cluster-RCT
N/A	Tanzania (Dodoma)	pregnant women	• Provide simple health education (obstetric danger signs, newborn danger signs, Individual birth preparedness, complication readiness) • Engage expecting parents (mother and father) with essential health information. • two-way communication	A quasi-experimental study with a control group is characterised explicitly as a "pre- and post-test with a control group."
T4MCH	Ghana	Pregnant women	• Automated messaging (SMS/voice messages)	Standard guidelines for reporting quasi-experimental studies using the Transparent Reporting of Evaluations with Non-randomized Design/Quasi-Experimental Study Design (TREND)
N/A	Iraq	Pregnant women attending an antenatal clinic linked to Al Elwiya Maternity Teaching Hospital	• Automated SMS	Controlled experimental study
Mobile WACh NEO system	Kenya	Pregnant women were recruited from four different facilities in Kenya.	• Two-Way Communication • Automated Messaging • Support for Multiple Languages • Response Management • Participant Tracking • Cost-Free for Participants	RCT
N/A	Pakistan	Pregnant women enrolled in the trial conducted at Lady	• Multi-modal communication (SMS and automated voices) • Automated Delivery	RCT

		Willingdon Hospital in Lahore	• Data tracking	
Customised FrontLine SMS	Ethiopia	Women aged 15-49 years who had at least one child	• Automated messaging • Data exchange between CHW and CHW • Contraceptive stock management	Community-based RCT
Maternal Health Plus	Nigeria	Pregnant women attending ANC within the Ife-Ijesa zone.	• Automatic delivery of SMS • Two-Way Communication • Database Management • Language Preference	RCT
Liga Inan	Timor-Leste	Women aged 15-49 years with a child up to 24 months of age.	• Web-based platform connected to a GSM. • Automatic delivery of SMS • voice communication	Quasi-experimental design.
N/A	Uganda	Pregnant women and their partners	• Cloud-Based platform • Monitoring ANC-seeking behaviour. • Automatic delivery of SMS	Pragmatic randomized trial
SISPRENACEL	Brazil	Pregnant women	• Automatic delivery of SMS • Two-Way communication • Individualised interaction management (Chat-like format) • Researcher access • Private cloud deployment	A socio-technical approach using the prototype method.
N/A	Nigeria	Pregnant women	• Automatic delivery of SMS • Customisation (depending on the type of health service) • cloud server • Unique QR code for each user	Multi-centered RCT

N/A= Not Available

3.1.2 Detailed app descriptions

This sub-section comprehensively describes each application based on the extracted data. Essential intervention details, such as message content, sending frequencies, and the development tools used (see Table 3), are provided.

Table 3 Detailed app descriptions

Study ID	Content of messages	Frequency	Tools/resources employed for implementation	Duration of the intervention

01	Health education on danger signs in pregnancy, the importance of skilled delivery attendance, and reminders for upcoming antenatal care visits.	The frequency of the messages varied throughout the pregnancy, with an increase in frequency to weekly messages during the last four weeks before delivery.	Specific software name or platforms used for development is not mentioned	The study followed the women until 42 days post-delivery to assess the impact of the mobile phone intervention on perinatal outcomes
02	Obstetric and newborn danger signs & Birth preparedness & Complication readiness	First Trimester: One message per week. Second Trimester: Two messages per week. Third Trimester: Three messages per week.	Specific software name or platform used for development is not mentioned	From the initial ANC visit until the point of delivery
03	The messages include the importance of regular antenatal care visits, the benefits of facility-based deliveries, and the necessity of postnatal care.	weekly	Savana Signatures: design and execution of the project; Salasan Inc: technological framework; Mustimuhw Information Solutions: software solutions	August 1, 2017, to September 30, 2017.
04	General health messages, Reminders to visit PHCC, Nutritional advice, Lifestyle education.	Weekly, every Friday between 4 PM and 6 PM	forat-sms.com: Bulk messaging platform	Not specified
05	Critical information on pregnancy, birth planning, infant care, and emergency responses	From enrolment to 38 weeks gestation: weekly. From 38 weeks gestation to delivery: Daily. From delivery to 2 weeks postpartum: Mothers receive two messages per day to reinforce care practices and provide ongoing support	Detailed in another paper (Perrier et al., 2015)	From enrolment at 28-36 weeks gestation until six weeks postpartum
06	Information about prenatal care, reminders for ultrasound tests, encouragement to follow medical advice and attend scheduled appointments.	It is not specified, but it is mentioned that the app could manage diverse messaging needs across distinct stages of pregnancy.	SMS Service Provider: API SMSAll.pk Telephony software: For automated calls,	Two months

			Asterisk was used, coupled with a Primary Rate Interface (PRI) line to manage multiple concurrent calls.	
07	ANC reminders and Child immunisation	Reminder messages for ANC appointments were sent to health extension workers (HEWs) at specific gestational weeks (14, 24, 30, and 36). Reminders were sent to HEWs about upcoming vaccination appointments at 6, 10, 14 weeks, and nine months. HEWs would send a reminder a week before the monthly vaccination.	Mobile phones equipped with customised FrontLineSMS & Central server and Local network & Short-code System and GSM Modem subscription	September 2012 to October 2013: 13 months
08	Clinic reminders, Specific pregnancy-related health tips, general tips	Delivered periodically, based on the antenatal care appointment schedule of each participant.	Mobile devices, SMS Enabler version 2.5.5, A MySQL database	December 2013 to December 2014
09	Reminders for care-seeking and promoted safe pregnancy and delivery practices.	Messages were sent twice weekly, precisely every Monday and Thursday.	Mobile devices, web-based applications connected to a GSM gateway	Two years
10	Appointment reminders	Weekly	a cloud-based platform, AfricasTalking API	Nine months
11	information on antenatal care, pregnancy, and delivery topics	Not specified but likely according to pregnancy stages	client-server architecture, CakePHP, and MySQL for data storage, AdminLTE version 1.0 for GUI	April 2015 to May 2016
12	visit reminder messages.	SMS text reminder two days before their scheduled appointments. If clients did not attend their appointments, an additional reminder was	mobile application linked to a cloud server, with a unique QR code for each user	1st April to 30th June 2019

		sent seven days after the original appointment date as a defaulter tracing measure.		

GUI: Graphical User Interface; QR code: quick-response code; RCT: randomised controlled trial

3.2 Effectiveness Evidence (RQ2)

3.2.1 Overview of studies

Among the twelve studies, six primary outcomes were identified: improved attendance (found in 9 studies), increased knowledge (3 studies), skilled delivery attendance (4 studies), neonatal mortality reduction (1 study), reduced complications (1 study), and patient satisfaction (1 study). eTable 2 provides a detailed breakdown of the primary outcomes categorised by study design. Regarding the message content sent to participants (including women and, in one case, their male partners (Muhoza et al., 2022), the key themes revolved around appointment reminders (observed in 11 studies, representing 91.7% of cases), educational content (75% of cases), emergency or danger alerts (16.7% of cases), and combinations of these themes (66.7% of cases). eFigure 7 available in the supplementary elements illustrates the frequency of SMS content types across the different apps. For detailed content types per study, please refer to Table 3.

The SMS-sending frequency was consistent across the studies. In five studies, messages were sent weekly, while in other cases, the frequency was adjusted according to the pregnancy stage or specific contextual timing. For instance, in the setup described by Masoi and Kibusi (2019), the frequency varied by pregnancy stage: one message per week during the first trimester, two per week in the second trimester, and three per week in the third trimester. Variations like these were noted in eight studies, including some that used weekly SMS during certain phases or daily SMS from delivery to two weeks postpartum (Ronen et al., 2021). A common trend in apps using varied frequencies was a systematic increase in message intervals as the delivery date approached. Table 2 provides detailed information for each app. The intervention durations varied, with some lasting less than three months (16.7%), others ranging from 3 to 6 months (16.7%), some spanning 6 to 12 months (41.7%), and three studies exceeding 12 months (25%).

The breakdown of development tools or approaches for app implementation is as follows. An SMS gateway (26.67% usage rate among evaluated apps) facilitates the efficient delivery and receipt of text messages, making it suitable for large-scale messaging campaigns due to its simplicity (Watterson et al., 2015). Custom apps (36.67%) provide personalised features like interactive messaging and data analytics, demanding substantial development resources while offering significant customisation. Third-party platforms (16.67%) are pre-built solutions with scheduling and often analytics features but may lack the flexibility of custom apps. A combined approach (20% usage rate) combines the strengths of multiple tools, such as using a custom app for analytics along with an SMS gateway or third-party platform for messaging, allowing for simplicity, customisation, and scalability tailored to various SMS interventions (Iribarren et al.,

2017). The specific names and/or platforms used by each app (when provided in the corpus of the article) can be found in Table 2.

3.2.2 Study findings

Unsurprisingly, all the studies highlight the significant impact of SMS-based interventions on maternal healthcare. Lund et al. (2014) discovered a substantial rise in antenatal care (ANC) attendance, with women adhering to World Health Organization (WHO) recommendations of four or more visits. Likewise, the same was observed in others (Alhaidari et al., 2018; Atnafu et al., 2017; Muhoza et al., 2022; Nuhu et al., 2023). Moreover, Lund et al. (2014) observed an increase in skilled delivery attendance among urban women, with an odds ratio (OR) of 5.73 (95% CI: 1.51-21.81). Notably, it significantly reduced perinatal mortality, with an OR of 0.50 (95% CI: 0.27-0.93). Ronen et al. (2021), in the pilot phase (Hedstrom et al., 2022) of their ongoing randomised controlled study (Mobile WACh NEO RCT), identified that among women residing in areas with elevated rates of stillbirth, perinatal and infant mortality, increasing maternal age was the sole predictor of stillbirth. It is essential to highlight that, although we included their main study in our dataset, the results have not yet been compiled and published as of the writing of this paper. The trial concluded participant enrolment (5,020 participants) on June 30, 2022, and follow-up was scheduled to continue until February 2023 (Global WACh, 2022). Consequently, we relied on the pilot phase results (Hedstrom et al., 2022).

These studies underscore the efficacy of SMS-based interventions in enhancing maternal healthcare outcomes, particularly in low-resource settings in developing countries. Table 4 shows the different studies along with the effect sizes or statistical significance of the primary outcomes as reported in the content of the papers.

Table 4 Effectiveness evidence

Study	Main outcomes & significance	Conclusion
(Lund, Rasch, et al., 2014)	Significant effect on antenatal care attendance, with an odds ratio (OR) of 2.39 and a 95% confidence interval (CI) of 1.03 to 5.55. Increased skilled delivery attendance among urban women, with an OR of 5.73 and a 95% CI of 1.51 to 21.81. Significant reduction in perinatal mortality with the mobile phone intervention, with an OR of 0.50 and a 95% CI of 0.27 to 0.93.	The study illustrates that the mobile phone intervention effectively improved critical maternal health outcomes and significantly reduced perinatal mortality.
(Masoi & Kibusi, 2019)	Significant increase in knowledge about obstetric and newborn danger signs (large effect size 85%). Higher scores in birth preparedness and complication readiness (effect size of 90%).	The significant effect sizes in both primary outcomes suggest that the intervention had a robust impact on the participants.
(Nuhu et al., 2023)	Increase ANC attendance, with an average treatment effect (ATE) of about eighteen percentage points.	These results highlight the positive impact of the intervention on key maternal

	Increase in the number of women opting for facility-based delivery. The effect size was an increase of approximately fourteen percentage points. PNC attendance also increased with the intervention, showing an effect size of about twenty-seven percentage points, suggesting a substantial positive impact.	health outcomes, with significant increases in attendance and utilization of essential maternal and child health services.
(Alhaidari et al., 2018)	Over 85% of the participants in the intervention group expressed satisfaction with the SMS-based support. Statistically significant increase in the median number of ANC visits compared.	The intervention significantly increased engagement in ANC, and positive feedback was received from participants regarding satisfaction.
Ronen et al (pilot study (Hedstrom et al., 2022))	The stillbirth rate observed was sixteen per 1,000 pregnancies. There were seventeen neonatal deaths during the study period, leading to a neonatal mortality rate of 22 per 1,000 live births. The perinatal death rate (including stillbirths and neonatal deaths up to 6 days of age) was 36 per 1,000 pregnancies.	This pilot phase identified that among women residing in areas with elevated rates of stillbirth, perinatal, and infant mortality, increasing maternal age was the sole predictor of stillbirth.
(Batool et al., 2017)	Significant improvements in knowledge about pregnancy and childbirth. No significant difference in the number of follow-up visits among the groups.	The study found significant gains in knowledge about pregnancy among participants. Still, the impact of increasing follow-up visits was less clear due to the influence of social norms and logistical barriers.
(Atnafu et al., 2017)	Significant increase in the proportion of mothers attending more than four ANC visits in the intervention. Ezha (Treatment 1): increased from 45.32% to 59.84%; Abeshge (Treatment 2): increased from 15.8% to 31.5% ; Sodo (Control): decreased from 24.48% to 23.27% ; P-value: P<0.001 for Ezha and Abeshge. There was a significant increase in deliveries attended by skilled health workers in the intervention areas Ezha (Treatment 1): Increased from 26.79% to 55.23%; Abeshge (Treatment 2): Increased from 41.96% to 63.54% ; Sodo (Control): Increased from 21.79% to 52.05%. P<0.001 in Ezha, indicating robust improvement	These findings highlight the improvements in healthcare services delivered to mothers and children due to the mobile intervention, with the most significant impact seen in antenatal care attendance and skilled deliveries. However, limitations in the intervention's effectiveness were noted in contraceptive utilisation and immunization coverage.
(Omole et al., 2018)	There was a significant increase in the proportion of facility-based deliveries among the intervention (29%) and control groups (13%).	These results prove that the SMS-based intervention positively affected maternal health behaviour by significantly increasing the rate

	96.6% of participants in the intervention group expressed support for the SMS intervention as a platform for maternal health promotion.	of facility-based deliveries among pregnant women.
(Thompson et al., 2019)	No significant increase in the number of women receiving four or more antenatal care visits. (OR = 1.0 (95% CI: 0.54-0.9)). Significant increase in the likelihood of women having a skilled birth attendant present during delivery (OR = 1.9 (95% CI: 1.1-3.2)). Significant increase in the likelihood of women delivering in a health facility (OR= 1.9 (95% CI: 1.1-3.6)).	Overall, the Liga Inan program demonstrated substantial improvements in skilled birth attendance, facility deliveries, postpartum care, and newborn health checks, with varying degrees of effect size, but did not significantly impact antenatal care visits.
(Muhoza et al., 2022)	Increase in male involvement in ANC with a 50% adherence rate among male partners, meaning 10 out of the 20 male partners attended four consecutive antenatal visits. Improved ANC-seeking behaviour among pregnant mothers.	The results suggest that SMS-based interventions can positively impact male participation in ANC and improve pregnant mothers' attendance rates.
(Oliveira-Ciabati et al., 2017)	The system received a high overall score of 6.33 out of 7 in usability, with the highest scores in system usefulness (6.61) and the lowest in information quality (6.03). High engagement with 22,296 scheduled SMS delivered, received 1,249 messages from participants, and 1,823 SMS inquiries answered. The system could be adapted for national-level deployment	These results underscore the app's effectiveness in achieving high user satisfaction and engagement and the potential for broader application in maternal health interventions.
(Kawakatsu et al., 2020)	Significant increase in the return rate for child vaccinations in the intervention group (4.8% to 6.0% higher return rate). No significant differences were observed in the return rates for ANC and family planning services between the intervention and control groups (Adjusted odds ratios close to 1)	The results suggest that while SMS reminders can be a powerful tool for improving adherence to vaccination schedules, their effectiveness may vary across different types of health services, potentially influenced by factors such as the perceived urgency or importance of the service by recipients (Kawakatsu et al., 2020).

4 Conclusion

This review shows that mobile health interventions hold significant promise in improving maternal health outcomes, particularly in low-and middle-income countries (see eFig. 7). The interventions demonstrated positive effects on ANC attendance, health knowledge, and general

maternal health behaviours, underscoring the value of digital health tools in resource-limited settings. However, the effectiveness of these interventions varied widely and was influenced by factors such as the content and frequency of messages and the implementation tools used. Based on the proven efficacy of the apps, further research should focus on refining or replicating these interventions and exploring their long-term impact on maternal and child health outcomes. Continued efforts in this field can significantly reduce barriers to antenatal care and improve maternal and child health outcomes.

The data extraction and analyses were conducted by a single reviewer, which is a limitation of this study. That may introduce bias, as the process lacks the checks and balances of independent review by multiple researchers.

5 Declaration of competing interest

The authors have no conflicts of interest to declare relevant to this paper's content.

6 Acknowledgement

I am grateful for the initial assistance provided by a colleague who, wishing to remain anonymous generously offered access to necessary databases, allowing me to commence this review. I also thank Prof MM for facilitating access to comprehensive DBs, ensuring the continuity and completion of this work.

7 Funding

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8 Declaration of generative AI and AI-assisted technologies in the writing process

While preparing this work, the authors used Chat GPT 4 and 4o to improve readability and language. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

9 Authors' contribution

MK: Project administration, conceptualisation, methodology, Writing original draft preparation, data curation, formal analysis after paper selection. MM: Conceptualisation, Writing-reviewing, editing and supervision. All authors approved the final manuscript.

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11 Appendix

(See attached checklist file)

Supplementary tables and figures

eTable 1. Summary of search results

	PubMed	Scopus	Web of Science	The Cochrane Library	**AISeL**	**Google Scholar**		**Science Direct**	**Total**
Search done in	Title and Abstract	Title, Abstract and Keywords	Abstract	Title, Abstract and Keywords	All fields	All fields		All fields	N/A
Results (considered)	21	62	26	10	57	En	Fr	3207(200)	776
						4750 (200)	256(200)		
Suitable studies	3	1	0	0	1	5	0	2	12

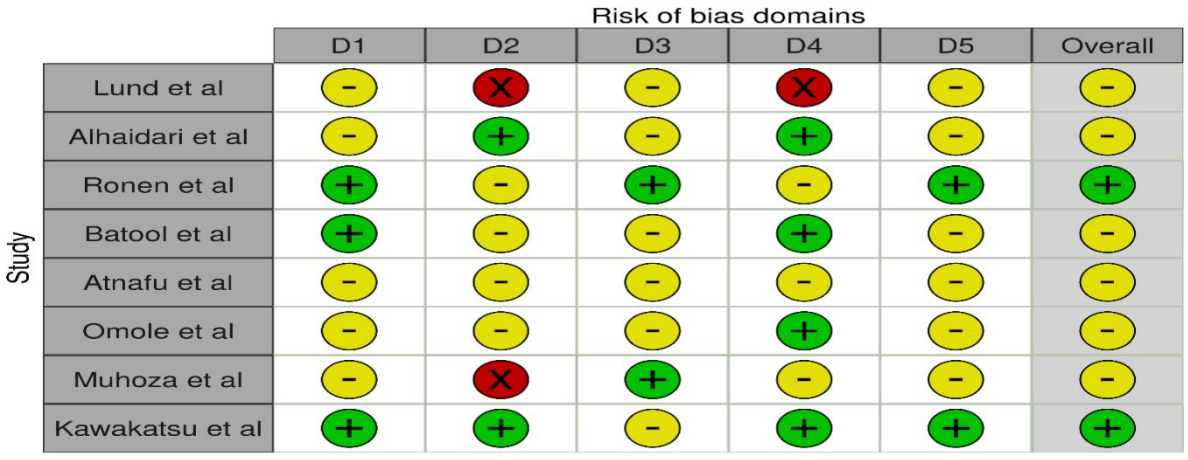
*eTable 2 Study design * Primary outcome*

		Primary outcome							Total
		Improved Attendance	Increased Knowledge	skilled delivery attendance	Neonatal mortality	Reduced Complications	patient satisfaction	Others	
Study design	RCT	7	1	2	1	0	1	1	8
	Non-RCT	2	1	2	0	1	0	1	3
	Other	0	1	0	0	0	0	1	1
Total		9	3	4	1	1	1	3	12

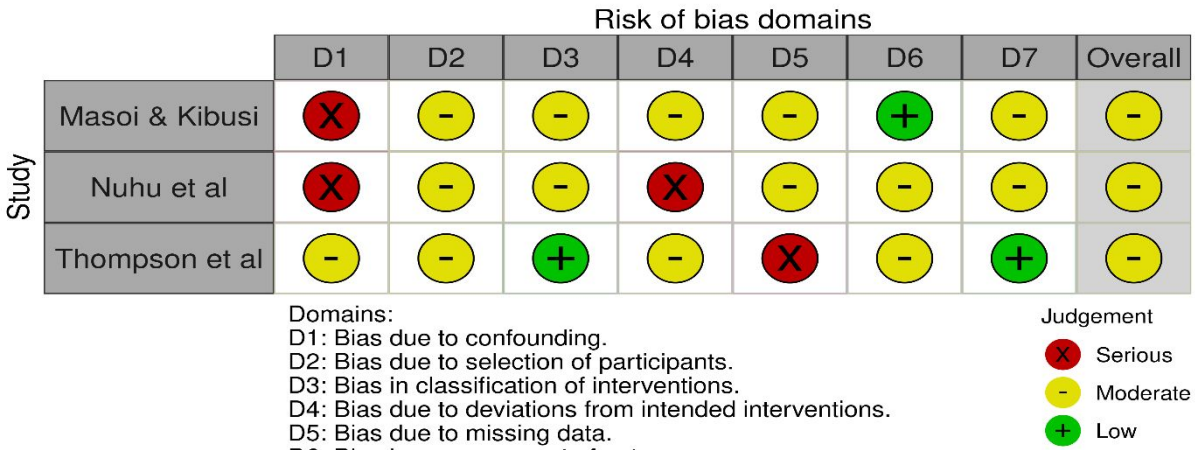
eTable 3 Data extraction form

Item	Value
Study Identification	
Study ID	Identification
Author name	Name(s) of the author(s)
Title	Title of the paper
Journal	Journal where the paper is published
Year	Year of publication
Study design	randomised controlled trial, observational study, etc
Country	The country where the study was conducted

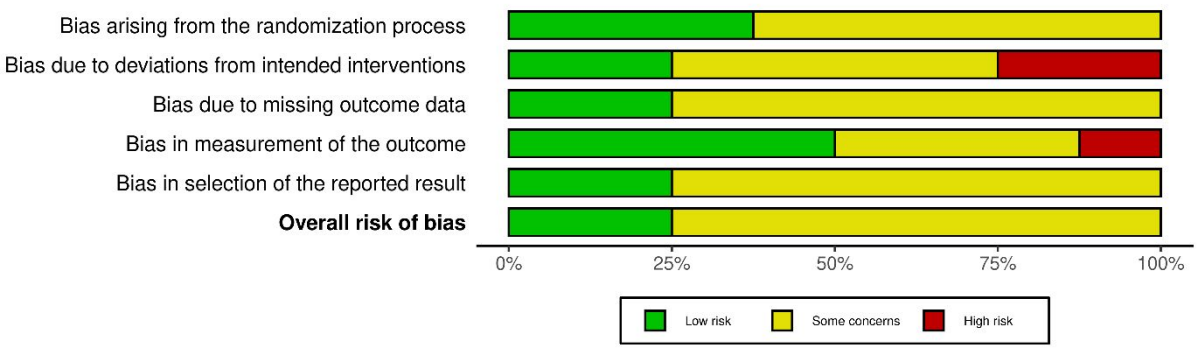
Study Participants	
Population description	Accurate description of the population
Sample size	value
Inclusion criteria	Main criteria reported
Exclusion criteria	Main criteria reported
Intervention Details	
Description of the SMS-based application	General description with purpose
Content of the SMS-based application	Content of the messages
Message sending frequency of the app	frequency of messages
Tools employed for the implementation of the app	Resources and tools employed for the implementation and/or requirements
Duration of the intervention	Duration as reported
Control or comparator interventions	As reported, if applicable
Outcomes	
Primary outcomes	Improve antenatal care attendance, knowledge enhancement, vaccination visits, satisfaction, etc.
Secondary outcomes	As reported, if applicable
Outcome measurement tools and methods	As reported
Results	
Key findings	Summary of results related to primary and secondary outcomes
Statistical significance	If applicable
Limitations	Limitations reported by the study
Quality Assessment	
Risk of bias assessment	For each study, depending on the study design



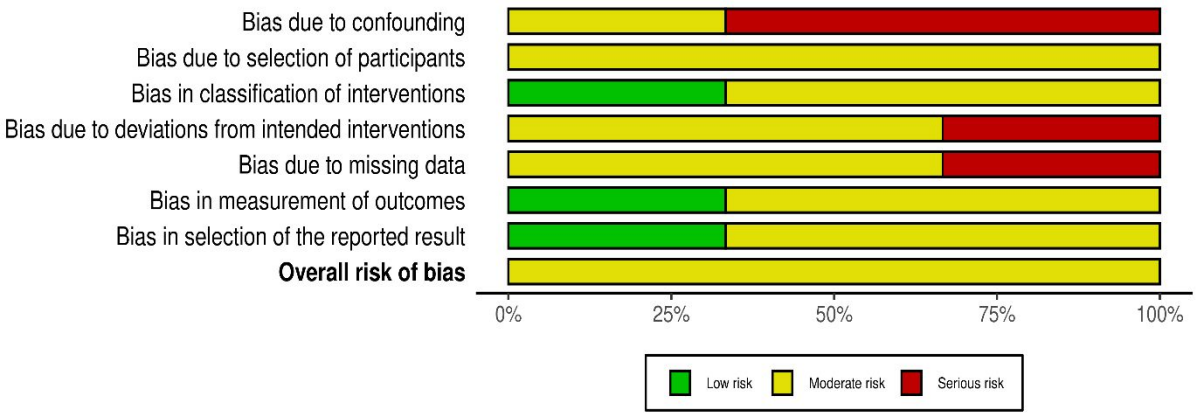
eFigure 1 Traffic-light plot ROB2



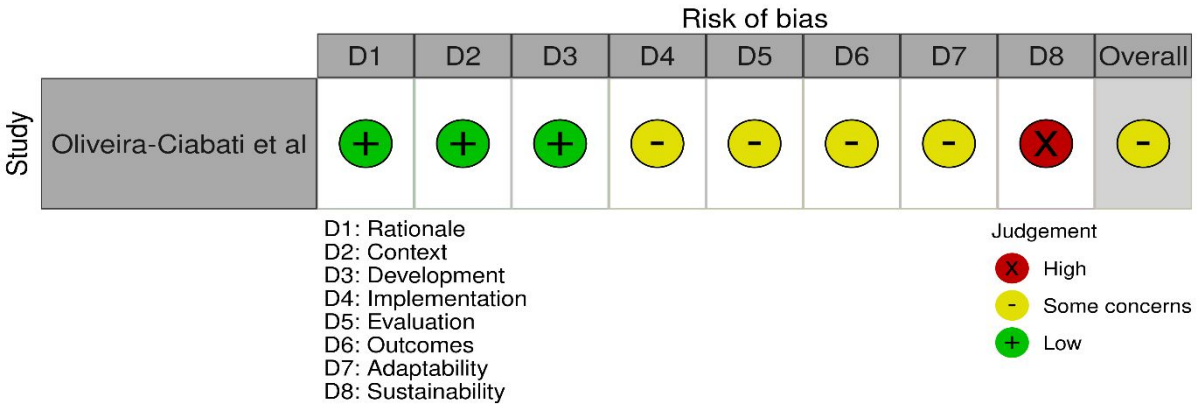
eFigure 2 Trafic-light plot ROBINS-I



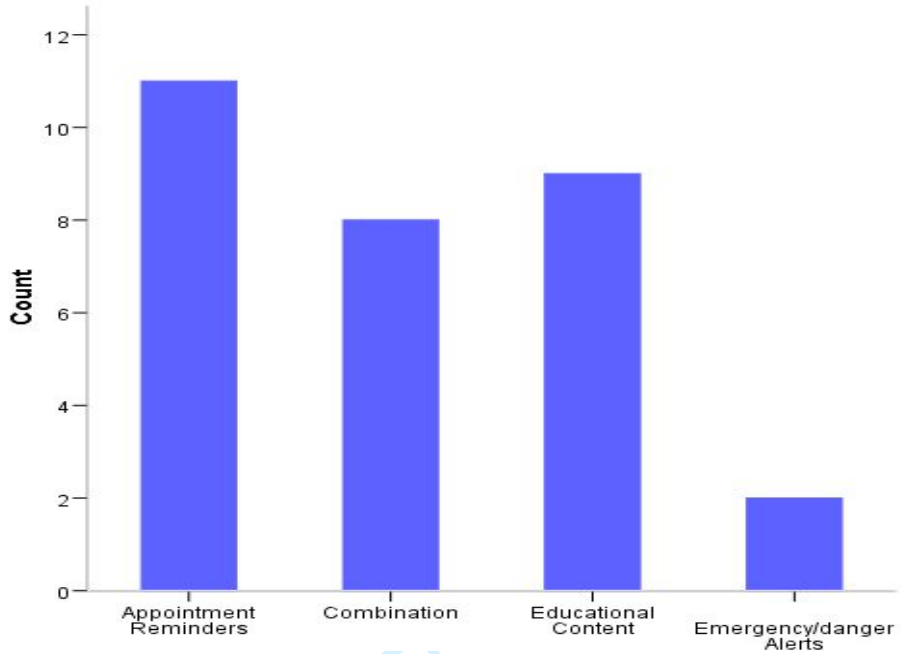
eFigure 3 Summary plot ROB2.



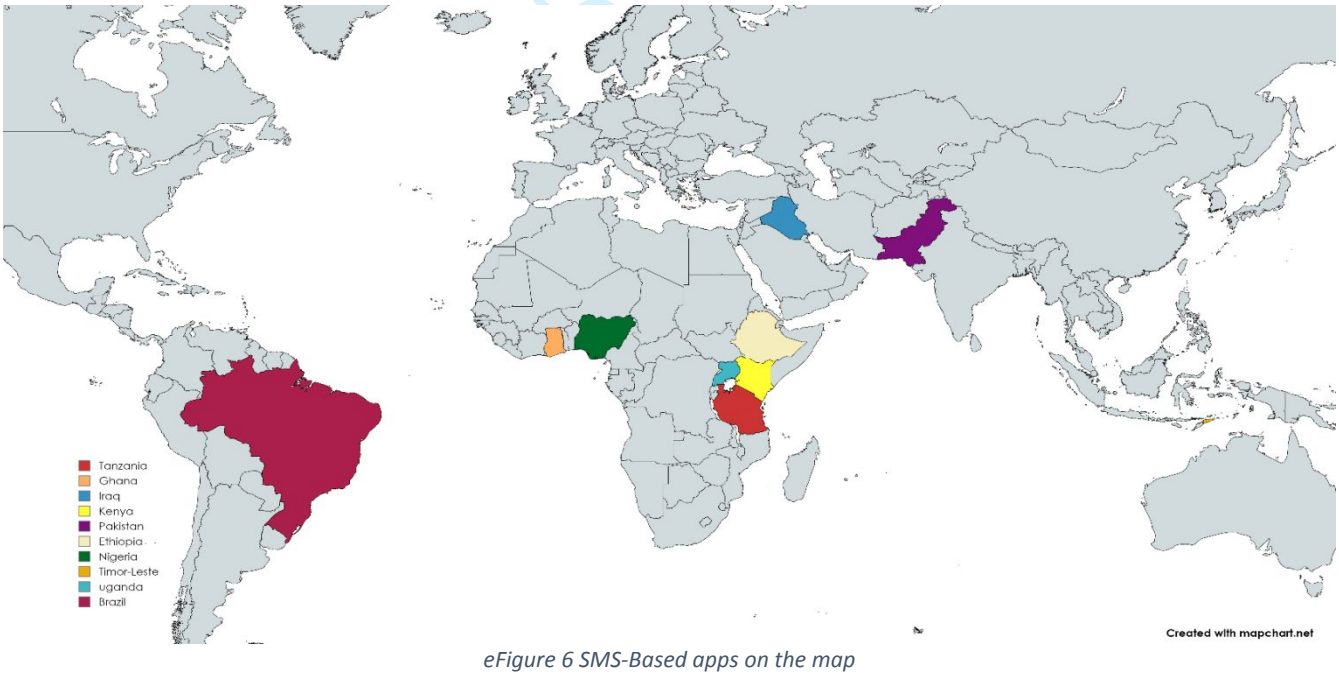
eFigure 4 Summary Plot ROBINS-I



eFigure 5 Traffic-light plot Checklist for reporting development.



eFigure 7 Content of SMS



eFigure 6 SMS-Based apps on the map

PRISMA 2020 for Abstracts Checklist

Section and Topic	Item #	Checklist item	Reported (Yes/No)
TITLE			
Title	1	Identify the report as a systematic review.	Yes
BACKGROUND			
Objectives	2	Provide an explicit statement of the main objective(s) or question(s) the review addresses.	Yes
METHODS			
Eligibility criteria	3	Specify the inclusion and exclusion criteria for the review.	Yes
Information sources	4	Specify the information sources (e.g. databases, registers) used to identify studies and the date when each was last searched.	Yes
Risk of bias	5	Specify the methods used to assess risk of bias in the included studies.	Yes
Synthesis of results	6	Specify the methods used to present and synthesise results.	Yes
RESULTS			
Included studies	7	Give the total number of included studies and participants and summarise relevant characteristics of studies.	Yes
Synthesis of results	8	Present results for main outcomes, preferably indicating the number of included studies and participants for each. If meta-analysis was done, report the summary estimate and confidence/credible interval. If comparing groups, indicate the direction of the effect (i.e. which group is favoured).	Yes
DISCUSSION			
Limitations of evidence	9	Provide a brief summary of the limitations of the evidence included in the review (e.g. study risk of bias, inconsistency and imprecision).	Yes
Interpretation	10	Provide a general interpretation of the results and important implications.	Yes
OTHER			
Funding	11	Specify the primary source of funding for the review.	Yes
Registration	12	Provide the register name and registration number.	N/A

PRISMA 2020 CHECKLIST

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Title
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Abstract
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Section 1
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Section 1 and 2.1
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Section 2.4
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Section 2.2
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Section 2.3
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Section 2.4, Figure 1
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Section 2.4, 2.5
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Section 2.5
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Section 2.5
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Section 2.8
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	NA
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Section 2.3
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	NA
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	NA
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	NA
	13e	Describe any methods used to explore possible causes of heterogeneity	NA

Section and Topic	Item #	Checklist item	Location where item is reported
		among study results (e.g. subgroup analysis, meta-regression).	
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	NA
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	NA
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	NA
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Figure 1 Flow diagram
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Figure 1
Study characteristics	17	Cite each included study and present its characteristics.	Section 2.7
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Section 2.8
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimates and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Tables Section 3
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Tables in Section 3
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	NA
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	NA
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	NA
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	Section 2.8
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	NA
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Section 3
	23b	Discuss any limitations of the evidence included in the review.	Refer to Section 3 and Section 4
	23c	Discuss any limitations of the review processes used.	Section 4
	23d	Discuss implications of the results for practice, policy, and future research.	Section 4
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	NA
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	NA
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	NA

Section and Topic	Item #	Checklist item	Location where item is reported
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Section 7
Competing interests	26	Declare any competing interests of review authors.	Section 5
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	All available with the first author on raisonable demand

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Enhancing antenatal care through SMS-Based interventions in developing countries: A systematic review of applications and their effectiveness

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Enhancing antenatal care through SMS-Based interventions in developing countries: A systematic review of applications and their effectiveness

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Abstract

Objectives: Pregnant women in low- and middle-income countries (LMICs), including Mali, often face challenges such as limited access to comprehensive health information and services. Mobile health (mHealth) interventions, particularly SMS-based interventions, have shown promise in addressing maternal health challenges. This review aims to provide an overview of existing SMS-based antenatal care (ANC) applications and assess their effectiveness in improving maternal and child health outcomes.

Design: A systematic literature review was conducted based on updated PRISMA 2020 guidelines.

Data sources: PubMed, Scopus, Web of Science, Cochrane Library, Association for Information Systems eLibrary, Direct Science, and Google Scholar were searched through 25 March 2024.

Eligibility criteria: Studies that focused on SMS-based interventions designed to improve antenatal care information and attendance, published in English or French, conducted in LMICs, and published between 2014 and 2024 were included. Exclusion criteria eliminated Studies that did not report primary outcomes or did not directly involve SMS-based interventions for ANC.

Data extraction and synthesis: Followed predefined criteria, and the risk of bias was assessed using the Cochrane risk-of-bias tool for randomised trials (RoB 2), the Risk Of Bias In Non-randomised Studies-of Interventions (ROBINS-I), and the Checklist for Reporting the Development and Evaluation of Complex Interventions in Healthcare (CReDECI), depending on study design. A subgroup analysis was performed to explore variations in outcomes by region and study design.

Results: The review identified a range of SMS-based interventions (N=12) that differed in target audience, message frequency (weekly, pregnancy stage oriented), and content (reminders, educational, and danger signs). Regional analysis highlighted significant research activity in East Africa but with mixed significance levels. Study design analysis revealed that randomised controlled trials (RCTs) yielded the most significant results, with five of eight

studies showing full significance, whereas quasi-experimental studies demonstrated consistent but less frequent effectiveness. Implementation tools varied from SMS gateways to custom applications and third-party platforms, with some interventions combining these approaches. SMS interventions positively impacted ANC attendance, maternal health knowledge, and behaviours, with effectiveness varying based on the intervention type, content, frequency, and the implementation approach.

Conclusion: SMS-based interventions have a potential to enhance ANC in LMICs by providing tailored health information and promoting healthy behaviours. Further research should focus on refining or replicating these interventions and exploring their long-term impacts on maternal and child health outcomes, particularly in underrepresented regions, and through diverse study designs.

Keywords: Antenatal Care, ANC, mHealth, SMS-Based intervention, LMICs

Strengths and limitations of this study

- This review utilised the PRISMA 2020 guidelines, ensuring a thorough and standardised approach to conducting the systematic review, thereby enhancing the transparency and reproducibility of the research process.
- The risk of bias in the included studies was meticulously assessed using three robust tools: RoB 2, ROBINS-I, and the CReDECI.
- Data extraction and synthesis followed predefined criteria to enhance the consistency and reliability.
- A notable limitation is that only one reviewer assessed the included papers.
- Quantitative statistical analysis typically performed in meta-analyses, such as pooled effect size calculation, was not undertaken, as the study was limited to a systematic review to inform our research focus.

1 Introduction

The lack of comprehensive health information and services for pregnant women is a significant challenge in improving maternal and child health in Mali and similar settings. Literature reports that knowledge of the place of consultation, treatment costs, pregnancy complications, and the place of antenatal care treatment significantly influence maternal mortality [1]. Additionally, regarding services, births attended by skilled health personnel correlate with maternal mortality in sub-Saharan Africa [2]. Poor antenatal and maternal health awareness among pregnant women contributes to inadequate health behaviours and care-seeking, causing avoidable morbidity and mortality.

Antenatal care (ANC) is a critical component of maternal healthcare that aims to monitor and enhance the health outcomes of pregnant women and their unborn children. Regular ANC visits enable healthcare providers to detect and manage potential health problems, educate women about pregnancy and childbirth, and advocate for healthy behaviours that benefit both the mother and the child [3–5]. Despite the global recognition of ANC's importance, significant challenges persist in ensuring comprehensive care for all pregnant women, particularly in low- and middle-income countries (LMICs). Studies have shown that maternal education, household income, and cultural beliefs significantly affect the utilisation of antenatal care services, with disparities in access and use across different socioeconomic and demographic groups [5,6].

Addressing these challenges requires targeted interventions to improve the access, awareness, and affordability of ANC services for pregnant women in these regions.

The rapid growth of mobile technology has led to innovative ways of increasing healthcare access and engaging patients. SMS-based systems have become vital for closing the information gap and boosting engagement with ANC services. These applications offer a platform for delivering timely, relevant information directly to the mobile phones of pregnant women, thus increasing awareness of the importance of ANC, reminding women of their upcoming appointments, and providing crucial health-related guidance [7–12]. Studies have demonstrated the potential of mobile health (mHealth) interventions to monitor prenatal care among pregnant women in LMICs [13] and have evaluated the effectiveness of SMS on focused ANC visits and skilled birth attendance in such settings [7]. Incorporating SMS-based interventions into maternal healthcare is a significant trend towards utilising mHealth solutions to enhance healthcare delivery and patient outcomes.

Despite rapid advancements in mobile health technologies, basic SMS remains a cornerstone in regions where limited Internet access and low smartphone penetration hinder the adoption of more complex systems. This review seeks to address the utility and effectiveness of SMS-based interventions in such settings, where even basic utilities such as consistent electricity or internet access may be unreliable. It examines the existence and scope of interventions using SMS-based interventions specifically tailored to improve the dissemination of ANC information and attendance of pregnant women at ANC visits in developing countries. Additionally, it assesses evidence concerning the effectiveness of these interventions in fostering maternal and neonatal health outcomes.

In the current global public health landscape, disparity in maternal healthcare access between developed and developing countries highlights the critical need for accessible and effective interventions. The urgency for accessible and effective interventions is underscored by persistent disparities in maternal healthcare access and outcomes, particularly in underserved communities. By exploring the impact of SMS-based applications on metrics such as antenatal care visit attendance and skilled birth attendance, this review aims to illuminate the potential of digital interventions to complement traditional ANC services and contribute to the reduction of maternal and neonatal morbidity and mortality, thereby supporting public health goals [14], and with the ultimate aim of contributing to the broader global health new narrative as suggested in [15] i.e., health, sustainability and transformation.

The remainder of this paper is organised as follows. In the second section, the methodology used is detailed by describing the research question, data sources for the study, search strategy employed, selection criteria of the studies included in the dataset, and data extraction process. In this section, we present the tools used for the analysis of the dataset, data characteristics, and risk-of-bias assessment process. In the third section, the results are presented, and they are discussed in section four. Finally, we conclude the paper in section five.

2 Methodology

A systematic approach was employed to identify and evaluate significant findings concerning the use of SMS-based interventions to improve ANC in developing countries, as documented in peer-reviewed online French and English journals over the past decade. To ensure a thorough and effective review process, we followed the updated guidelines outlined in the 2020 edition of Preferred Reporting Items for Systematic reviews and Meta-Analyses [16]. The PRISMA 2020 Abstracts and Checklist items can be accessed from the appendix.

2.1 Research questions

The objectives of this study were to address the following research questions:

RQ1: What are the characteristics and availability of SMS-based applications developed between 2014 and 2024 to enhance antenatal care information and attendance among pregnant women in low- and middle-income countries?

RQ2: How effective are these SMS-based applications in improving antenatal care information and attendance among pregnant women in low- and middle-income countries compared with usual care?

2.2 Data sources

The search included the following electronic databases or search engines: PubMed (last searched 19 March 2024), Scopus (last searched 21 March 2024), Web of Science (last searched 22 March 2024), Cochrane Library (last searched 20 March 2024), Association for Information Systems eLibrary (AISeL) (last searched 20 March 2024), Direct Science (last searched 21 March 2024), and Google Scholar (last searched 25 March 2024). These searches were conducted to ensure the inclusion of the most up-to-date and relevant literature.

2.3 Search strategy

The formulated research questions guided the construction of the search strings, leading to their combination through logical connectors. The resulting string was [("SMS-based applications" OR "text messaging" OR "mobile health" OR "mHealth") AND ("antenatal care" OR "prenatal care" OR "pregnancy care" OR "ANC") AND ("developing countries" OR "low-income countries" OR "resource-limited settings")]. This process was adapted according to the requirements of each electronic database. Science Direct, for example, did not accept more than eight logical connectors in a single search. The author translated the search string into French by combining words and expressions used in the English search. The resulting string was *("applications basées sur SMS" OU "messagerie texte" OU "santé mobile" OU "mSanté") ET ("soins prénatals" OU "soins anténataux" OU "soins pendant la grossesse" OU "CPN") ET ("pays en développement" OU "pays à faible revenu" OU "contextes à ressources limitées")*. The process used for searching and selecting different publications is summarised in a Diagram Flow and presented in Fig. 1. The flow diagram of the search was created using the R-developed online tool by Haddaway et al. [17]. eTable 1 in the supplementary files summarises the full search strategy, and eTable 2 details the results per database.

2.4 Selection criteria

Initially, 776 publications were found, as detailed in eTable 2. Additional inclusion and exclusion criteria were applied to shift the initial findings to pinpoint studies pertinent to our goals. Consequently, these publications underwent a rigorous screening process based on the inclusion and exclusion criteria. These criteria were defined to ensure the relevance and quality of the analysed data. The study design criteria included randomised controlled trials (RCTs), quasi-experimental, observational, and qualitative studies that provided data on the implementation, usage, and outcomes of SMS-based ANC interventions. Editorials, reviews, opinion pieces, and studies lacking primary data or clear outcomes related to ANC and SMS-based interventions were excluded. The population criteria focused on studies involving pregnant women in LMICs encompassing women of all ages, ethnicities, and stages of pregnancy. For the intervention criteria, the studies needed to focus on SMS-based systems designed to improve ANC information and attendance. These included interventions promoting health education, appointment reminders, health monitoring, and support through text messaging. Studies that did not specifically use SMS-based communication as a primary method for delivering antenatal care information or support were excluded. Criteria such as comparators, outcomes, publication dates, and language were also used. eTable 3 in the supplementary files provides a detailed description of the inclusion and exclusion criteria used in this review, along with a rationale for each criterion, allowing a full understanding of the justifications for both including and excluding certain studies. In the subsequent phase, the process involved verifying the presence of duplicate papers given that multiple databases were used for the search. This resulted in identifying and removing 11 duplicate documents from the dataset. Full texts of papers were then retrieved and checked. Following this meticulous selection phase, a final count of 12 papers was deemed appropriate and suitable for review (see

Fig.1).

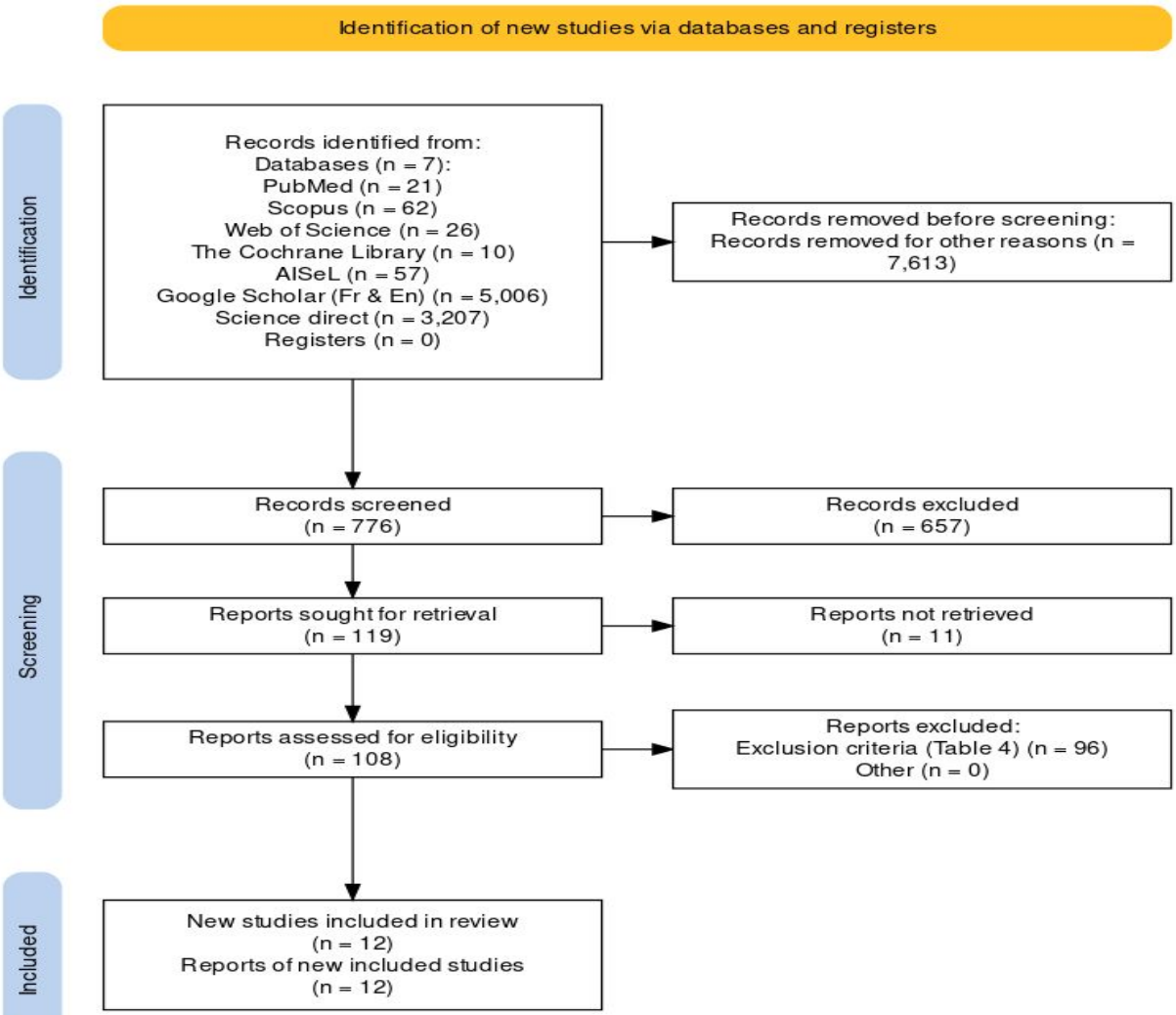

Figure 1 Flow Diagram of the search.

2.5 Data extraction

After completing the selection process, we manually extracted information from the selected papers. The study identification items extracted included the author names, title of the paper, journal of publication, year of publication, study design type, and the country where the study was conducted. Details regarding the study participants were also extracted, including an accurate description of the study population, sample size, and primary inclusion and exclusion criteria. Information on the intervention details extracted includes a general description and purpose of the SMS-based application as presented in the paper, the content of the messages, the frequency of message sending, the resources and tools employed for the implementation, and the duration of the intervention. Additionally, control or comparator interventions were retrieved as reported, if applicable. The reported outcomes (primary and secondary) were then extracted. Key findings related to the indicated outcomes, statistical significance where applicable, and any reported limitations were also extracted. The complete data extraction form is provided in the supplementary eTable 4.

2.6 Tools and analysis

The data set was managed using the open-source desktop-based application Mendeley version 1.19.8. Moreover, the items extracted were stored and used to make descriptive statistics using JabRef (version 5.13), Microsoft 365 Excel app (version 2403) and IBM SPSS Statistics 20.

2.7 Patient and public involvement

None.

2.8 Data characteristics

A bibliometric overview of the selected papers is described in Table 1. Each paper was assigned a numerical identifier and categorised in Table 1 according to the year of publication, from oldest to most recent and by source.

2.9 Risk of Bias Assessment

In this study, the dataset comprised of 12 scholarly articles. Each article was evaluated for potential bias, with assessment criteria varying according to the study design. Three distinct tools were utilised to conduct this assessment: Version 2 of the Cochrane risk-of-bias tool for randomised trials (RoB 2) [26] was applied to eight studies, the Risk Of Bias In Non-randomised Studies - of Interventions (ROBINS-I) tool [27] to three studies, and the Checklist for Reporting the Development and Evaluation of Complex Interventions in Healthcare [28] was conveniently used for one study. Visual representations of the assessments, including traffic light plots (see eFig. 1 and 2) and summary plots (see eFig. 3 and 4), were created for the two groups (RoB 2 and ROBINS-I). Refer to eFig. 5 for assessment of the study against the checklist. These plots were generated utilising the Risk Of Bias VISualisation (ROBVIS) tool [29]. The overall risk assessment for the papers was categorised as 'some concerns'. Consequently, we did not exclude any of the documents included due to the absence of many significant high/critical issues with individual papers.

Table 1 Bibliometric overview

ID	Author(s)	Title	Journal/Conf	Country (region)	Year	Source
01	Lund et al [12]	Mobile Phone Intervention Reduces Perinatal Mortality in Zanzibar: Secondary Outcomes of a Cluster Randomized Controlled Trial	JMIR mhealth and uhealth	Tanzania (Zanzibar)	2014	
02	Masoi & Kibusi [9]	Improving pregnant women's knowledge on danger signs and birth preparedness practices using an interactive mobile messaging alert system in Dodoma region, Tanzania: a controlled quasi-experimental study	Reproductive Health	Tanzania (Dodoma)	2019	

03	Nuhu et al [8]	Impact of mobile health on maternal and child health service utilization and continuum of care in Northern Ghana	Scientific Reports	Ghana	2023	PubMed
04	Alhaidari et al [18]	Feasibility and acceptability of text messaging to support antenatal healthcare in Iraqi pregnant women: A pilot study.	Journal of Perinatal Medicine	Iraq	2018	Scopus
05	Ronen et al [10]	Evaluation of a two-way SMS messaging strategy to reduce neonatal mortality: rationale, design and methods of the Mobile WACh NEO randomised controlled trial in Kenya.	BMJ open	Kenya	2021	AISeL
06	Batool et al [19]	Maternal complications: Nuances in mobile interventions for maternal health in urban Pakistan	Proceedings of the Ninth International Conference on Information and Communication Technologies and Development	Pakistan	2017	Google Scholar
07	Atnafu et al [20]	The role of mHealth intervention on maternal and child health service delivery: findings from a randomized controlled field trial in rural Ethiopia	mHealth	Ethiopia	2017	
08	Omole et al [21]	The effect of mobile phone short message service on maternal health in south-west Nigeria	The International Journal of Health Planning and Management	Nigeria	2018	
09	Thompson et al [22]	Connecting mothers to care: Effectiveness and scale-up of an mHealth program in Timor-Leste.	Journal of Global Health	Timor-Leste	2019	

10	Muhoza et al [23]	A mobile-based technology to improve male involvement in antenatal care.	Kabale University Interdisciplinary Research Journal	Uganda	2022	
11	Oliveira-Ciabati et al [24]	SISPRENACEL - MHealth tool to empower PRENACEL strategy.	Procedia Computer Science	Brazil	2017	Science Direct
12	Kawakatsu et al [25]	Cost-effectiveness of SMS appointment reminders in increasing vaccination uptake in Lagos, Nigeria: A multi-centered randomised controlled trial	Vaccine	Nigeria	2020	

3 Results

3.1 SMS App Inventory (RQ1)

3.1.1 Overview of apps

The dataset consists of 12 applications. These ranged from basic, one-way SMS-sending apps to more complex, bidirectional communication platforms that connected pregnant women with healthcare providers throughout and sometimes beyond the pregnancy period. Table 2 provides an overview of the SMS-based applications identified in the literature review, offers a snapshot of their key features and implementation contexts. The table includes details on each app's target population, the key features, and the study design employed to evaluate its effectiveness. App names are given where the authors gave specific names to their developed apps.

Table 2 Overview of apps

App name	Country (region)	Target population	Key features	Study design
The Wired Mothers	Tanzania (Zanzibar)	Pregnant women attending antenatal care at 24 primary health care facilities across six districts on the island of Unguja	• Unidirectional text messaging • a mobile phone voucher system for two-way communication between pregnant women and their primary health care providers.	Pragmatic, cluster-RCT
N/A	Tanzania (Dodoma)	pregnant women	• Provide simple health education (obstetric danger signs, newborn danger signs, Individual birth	A quasi-experimental study with a control group is characterised explicitly as a "pre-

			preparedness, complication readiness) • Engage expecting parents (mother and father) with essential health information. • two-way communication	and post-test with a control group."
T4MCH	Ghana	Pregnant women	• Automated messaging (SMS/voice messages)	Standard guidelines for reporting quasi-experimental studies using the Transparent Reporting of Evaluations with Non-randomized Design/Quasi-Experimental Study Design (TREND)
N/A	Iraq	Pregnant women attending an antenatal clinic linked to Al Elwiya Maternity Teaching Hospital	• Automated SMS	Controlled experimental study
Mobile WACh NEO system	Kenya	Pregnant women were recruited from four different facilities in Kenya.	• Two-Way Communication • Automated Messaging • Support for Multiple Languages • Response Management • Participant Tracking • Cost-Free for Participants	RCT
N/A	Pakistan	Pregnant women enrolled in the trial conducted at Lady Willingdon Hospital in Lahore	• Multi-modal communication (SMS and automated voices) • Automated Delivery • Data tracking	RCT
Customised FrontLine SMS	Ethiopia	Women aged 15-49 years who had at least one child	• Automated messaging • Data exchange between CHW and CHW • Contraceptive stock management	Community-based RCT
Maternal Health Plus	Nigeria	Pregnant women attending ANC within the Ife-Ijesa zone.	• Automatic delivery of SMS • Two-Way Communication • Database Management • Language Preference	RCT
Liga Inan	Timor-Leste	Women aged 15-49 years with a child up to 24 months of age.	• Web-based platform connected to a GSM.	Quasi-experimental design.

			• Automatic delivery of SMS • voice communication	
N/A	Uganda	Pregnant women and their partners	• Cloud-Based platform • Monitoring ANC-seeking behaviour. • Automatic delivery of SMS	Pragmatic randomized trial
SISPRENACEL	Brazil	Pregnant women	• Automatic delivery of SMS • Two-Way communication • Individualised interaction management (Chat-like format) • Researcher access • Private cloud deployment	A socio-technical approach using the prototype method.
N/A	Nigeria	Pregnant women	• Automatic delivery of SMS • Customisation (depending on the type of health service) • cloud server • Unique QR code for each user	Multi-centered RCT

N/A= Not Available

3.1.2 Detailed app descriptions

This subsection comprehensively describes each application based on extracted data. Essential intervention details, such as message content, sending frequencies, and the development tools used (see Table 3), are provided.

Table 3 Detailed app descriptions

Study ID	Content of messages	Frequency	Tools/resources employed for implementation	Duration of the intervention
01	Health education on danger signs in pregnancy, the importance of skilled delivery attendance, and reminders for upcoming antenatal care visits.	The frequency of the messages varied throughout the pregnancy, with an increase in frequency to weekly messages during the last four weeks before delivery.	Specific software name or platforms used for development is not mentioned	The study followed the women until 42 days post-delivery to assess the impact of the mobile phone intervention on perinatal outcomes
02	Obstetric and newborn danger signs & Birth	First Trimester: One message per week.	Specific software name or platform used	From the initial ANC visit until the point of delivery

	preparedness & Complication readiness	Second Trimester: Two messages per week. Third Trimester: Three messages per week.	for development is not mentioned	
03	The messages include the importance of regular antenatal care visits, the benefits of facility-based deliveries, and the necessity of postnatal care.	weekly	Savana Signatures: design and execution of the project; Salasan Inc: technological framework; Mustimuhw Information Solutions: software solutions	August 1, 2017, to September 30, 2017.
04	General health messages, Reminders to visit PHCC, Nutritional advice, Lifestyle education.	Weekly, every Friday between 4 PM and 6 PM	forat-sms.com: Bulk messaging platform	Not specified
05	Critical information on pregnancy, birth planning, infant care, and emergency responses	From delivery to 2 weeks postpartum, mothers get two daily messages to bolster care practices and offer continuous support.	Detailed in another paper [30]	From enrolment at 28-36 weeks gestation until six weeks postpartum
06	Information about prenatal care, reminders for ultrasound tests, encouragement to follow medical advice and attend scheduled appointments.	It is not specified, but it is mentioned that the app could manage diverse messaging needs across distinct stages of pregnancy.	SMS Service Provider: API SMSAll.pk Telephony software: For automated calls, Asterisk was used, coupled with a Primary Rate Interface (PRI) line to manage multiple concurrent calls.	Two months
07	ANC reminders and Child immunisation	Health extension workers (HEWs) received ANC appointment reminders at gestational weeks 14, 24, 30, and 36. Vaccination appointment reminders were sent at 6, 10, and 14 weeks, and nine months. HEWs then sent a reminder one week prior to monthly vaccinations.	Mobile phones equipped with customised FrontLineSMS & Central server and Local network & Short-code System and GSM Modem subscription	September 2012 to October 2013: 13 months

08	Clinic reminders, Specific pregnancy-related health tips, general tips	Delivered periodically, based on the antenatal care appointment schedule of each participant.	Mobile devices, SMS Enabler version 2.5.5, A MySQL database	December 2013 to December 2014
09	Reminders for care-seeking and promoted safe pregnancy and delivery practices.	Messages were sent twice weekly, precisely every Monday and Thursday.	Mobile devices, web-based applications connected to a GSM gateway	Two years
10	Appointment reminders	Weekly	a cloud-based platform, AfricasTalking API	Nine months
11	information on antenatal care, pregnancy, and delivery topics	Not specified but likely according to pregnancy stages	client-server architecture, CakePHP, and MySQL for data storage, AdminLTE version 1.0 for GUI	April 2015 to May 2016
12	visit reminder messages.	SMS text reminder two days before their scheduled appointments. If clients did not attend their appointments, an additional reminder was sent seven days after the original appointment date as a defaulter tracing measure.	mobile application linked to a cloud server, with a unique QR code for each user	1st April to 30th June 2019

GUI: Graphical User Interface; QR code: quick-response code; RCT: randomised controlled trial

3.2 Effectiveness Evidence (RQ2)

3.2.1 Overview of studies

Among the twelve studies, six primary outcomes were identified: improved attendance (found in 9 studies), increased knowledge (3 studies), skilled delivery attendance (4 studies), neonatal mortality reduction (1 study), reduced complications (1 study), and patient satisfaction (1 study). eTable 5 provides a detailed breakdown of the primary outcomes categorised by study design. Regarding the message content sent to participants (including women and, in one case, their male partners [23], the key themes revolved around appointment reminders (observed in 11 studies, representing 91.7% of cases), educational content (75% of cases), emergency or danger alerts (16.7% of cases), and combinations of these themes (66.7% of cases). eFig 6 available in the supplementary elements illustrates the frequency of SMS content types across the different apps. For the detailed content types per study, please refer to Table 3.

The SMS-sending frequency was consistent across the studies. In five studies, messages were sent weekly, while in other cases, the frequency was adjusted according to the pregnancy stage or specific contextual timing. For instance, in the setup described by Masoi and Kibusi [9], the

frequency varied by pregnancy stage: one message per week during the first trimester, two per week in the second trimester, and three per week in the third trimester. These variations were noted in eight studies, including some that used weekly SMS during certain phases or daily SMS from delivery to two weeks postpartum [10]. A common trend in apps using varied frequencies was a systematic increase in message intervals as the delivery date approached. Table 2 provides detailed information on each application. The intervention durations varied, with some lasting less than three months (16.7%), others ranging from 3 to 6 months (16.7%), some spanning 6 to 12 months (41.7%), and three studies exceeding 12 months (25%).

The breakdown of development tools or approaches for app implementation is as follows. An SMS gateway (26.67% usage rate among evaluated apps) facilitates the efficient delivery and receipt of text messages, making it suitable for large-scale messaging campaigns due to its simplicity [31]. Custom apps (36.67%) provide personalised features like interactive messaging and data analytics, demanding substantial development resources while offering significant customisation. Third-party platforms (16.67%) are pre-built solutions with scheduling and often analytics features but may lack the flexibility of custom apps. A combined approach (20% usage rate) combines the strengths of multiple tools, such as using a custom app for analytics along with an SMS gateway or a third-party platform for messaging, allowing for simplicity, customisation, and scalability tailored to various SMS interventions [32]. The specific names and/or platforms used by each app (when provided in the article corpus) are listed in Table 2.

3.2.2 Study findings

Unsurprisingly, all studies highlighted the significant impact of SMS-based interventions on maternal healthcare. Lund et al. [12] discovered a substantial rise in ANC attendance, with women adhering to the World Health Organization (WHO) recommendations of four or more visits. The same was observed in other studies [8,18,20,23]. Moreover, they [12] observed an increase in skilled delivery attendance among urban women, with an odds ratio (OR) of 5.73 (95% CI: 1.51-21.81). Notably, it significantly reduced perinatal mortality, with an OR of 0.50 (95% CI: 0.27-0.93). Ronen et al. [10], in the pilot phase [33] of their ongoing randomised controlled study (Mobile WACh NEO RCT), identified that among women residing in areas with elevated rates of stillbirth, perinatal and infant mortality, increasing maternal age was the sole predictor of stillbirth. It is essential to highlight that, although we included their main study in our dataset, the results have not yet been compiled and published as of the writing of this paper. The trial concluded with participant enrolment (5,020 participants) on 30 June 2022 and follow-up was scheduled to continue until February 2023 [34]. Consequently, we relied on the pilot-phase results [33]. Table 4 shows the different studies along with the effect sizes or statistical significance of the primary outcomes as reported in the content of the papers.

3.2.3 Subgroup analysis

Subgroup analysis explored the distribution and outcomes of the interventions across regions, study designs, and intervention types, providing a better understanding of the factors influencing their effectiveness.

3.2.3.1 Regional distribution and significance

Regional distribution analysis revealed notable differences in the number of studies, outcomes, and study-level significance across global regions. Five studies were conducted in East Africa (Ethiopia, Kenya, Tanzania, and Uganda). Of these studies, four reported outcomes that were statistically significant [9,12,20,23], and one did not indicate significance (pilot)[33]. This highlights the region's robust research activity. In West Africa (Ghana and Nigeria), three studies were significant, emphasising the effectiveness of interventions in this region [8,21]. Asia (Pakistan and Timor-Leste), the Middle East (Iraq), and South America (Brazil) are underrepresented with only one study per country.

3.2.3.2 Impact of study designs

Randomised controlled trials (RCTs) dominated the dataset, with eight studies spanning East and West Africa and Asia. Of these, five demonstrated all outcomes as significant, while two reported partial significance (see eTable 6). This reflects the robustness of the RCT design in yielding significant findings, albeit with some variations. Quasi-experimental studies, the second most common design, include 3 studies from Ghana, Tanzania, and Timor-Leste. Two of these achieved full significance, while one fell under the 'not applicable' category. A sociotechnical approach using a prototype method is less common, as represented by a single study. It reports fully significant outcomes, indicating potential but limited generalisability due to their low frequency.

3.2.3.3 Effectiveness of intervention types

Intervention-type analysis revealed critical trends in the study's effectiveness and applicability. Mixed interventions (educational and reminders) are the most prevalent, with six studies across diverse regions including Africa, Asia, and the Middle East. Among these, five reported full significance, while one indicated partial significance. Educational messages, implemented in Brazil, Kenya, and Tanzania, are associated with three studies, of which two demonstrated significant outcomes and one was categorised as "not applicable." Reminders applied in Ethiopia, Nigeria, and Uganda show similar proportions, with two studies achieving full significance and one partial significance (refer to eFig. 7).

Table 4 Effectiveness evidence

Study	Main outcomes & significance	Conclusion
[12]	Significant effect on antenatal care attendance, with an odds ratio (OR) of 2.39 and a 95% confidence interval (CI) of 1.03 to 5.55. Increased skilled delivery attendance among urban women, with an OR of 5.73 and a 95% CI of 1.51 to 21.81. Significant reduction in perinatal mortality with the mobile phone intervention, with an OR of 0.50 and a 95% CI of 0.27 to 0.93.	The study illustrates that the mobile phone intervention effectively improved critical maternal health outcomes and significantly reduced perinatal mortality.
[9]	Significant increase in knowledge about obstetric and newborn danger signs (large effect size 85%). Higher scores in birth preparedness and complication readiness (effect size of 90%).	The significant effect sizes in both primary outcomes suggest that the intervention had a robust impact on the participants.

[8]	Increase ANC attendance, with an average treatment effect (ATE) of about eighteen percentage points. Increase in the number of women opting for facility-based delivery (14%). PNC attendance also increased with the intervention (27%).	The results underscore the intervention's positive effect on maternal health, notably increasing attendance and utilisation of essential maternal and child health services.
[18]	Over 85% of the participants in the intervention group expressed satisfaction with the SMS-based support. Statistically significant increase in the median number of ANC visits compared.	The intervention significantly increased engagement in ANC, and positive feedback was received from participants regarding satisfaction.
[33]	The stillbirth rate observed was sixteen per 1,000 pregnancies. There were seventeen neonatal deaths during the study period, leading to a neonatal mortality rate of 22 per 1,000 live births. The perinatal death rate (including stillbirths and neonatal deaths up to 6 days of age) was 36 per 1,000 pregnancies.	This pilot phase identified that among women residing in areas with elevated rates of stillbirth, perinatal, and infant mortality, increasing maternal age was the sole predictor of stillbirth.
[19]	Significant improvements in knowledge about pregnancy and childbirth. No significant difference in the number of follow-up visits among the groups.	The study revealed substantial knowledge gains about pregnancy among participants, but the effect of increasing follow-up visits remained ambiguous due to social norms and logistical challenges.
[20]	Significant increase in the proportion of mothers attending more than four ANC visits in the intervention. Ezha (Treatment 1): increased from 45.32% to 59.84%; Abeshge (Treatment 2): increased from 15.8% to 31.5% ; Sodo (Control): decreased from 24.48% to 23.27% ; P-value: P<0.001 for Ezha and Abeshge. There was a significant increase in deliveries attended by skilled health workers in the intervention areas Ezha (Treatment 1): Increased from 26.79% to 55.23%; Abeshge (Treatment 2): Increased from 41.96% to 63.54% ; Sodo (Control): Increased from 21.79% to 52.05%. P<0.001 in Ezha, indicating robust improvement	These findings highlight the improvements in healthcare services delivered to mothers and children due to the mobile intervention, with the most significant impact seen in antenatal care attendance and skilled deliveries. However, limitations in the intervention's effectiveness were noted in contraceptive utilisation and immunisation coverage.
[21]	There was a significant increase in the proportion of facility-based deliveries among the intervention (29%) and control groups (13%). 96.6% of participants in the intervention group expressed support for the SMS intervention as a platform for maternal health promotion.	The intervention significantly improved maternal health behaviour by increasing the rate of facility-based deliveries among pregnant women.

[22]	No significant increase in the number of women receiving four or more antenatal care visits. (OR = 1.0 (95% CI: 0.54-0.9)). Significant increase in the likelihood of women having a skilled birth attendant present during delivery (OR = 1.9 (95% CI: 1.1-3.2)). Significant increase in the likelihood of women delivering in a health facility (OR= 1.9 (95% CI: 1.1-3.6)).	The Liga Inan program significantly improved skilled birth attendance, facility deliveries, postpartum care, and newborn health checks, though it did not notably affect antenatal care visits.
[23]	Increase in male involvement in ANC with a 50% adherence rate among male partners, meaning 10 out of the 20 male partners attended four consecutive antenatal visits. Improved ANC-seeking behaviour among pregnant mothers.	The results suggest that SMS-based interventions can positively impact male participation in ANC and improve pregnant mothers' attendance rates.
[24]	The system received a high overall score of 6.33 out of 7 in usability, with the highest scores in system usefulness (6.61) and the lowest in information quality (6.03). High engagement with 22,296 scheduled SMS delivered, received 1,249 messages from participants, and 1,823 SMS inquiries answered. The system could be adapted for national-level deployment	These results underscore the app's effectiveness in achieving high user satisfaction and engagement and the potential for broader application in maternal health interventions.
[25]	Significant increase in the return rate for child vaccinations in the intervention group (4.8% to 6.0% higher return rate). No significant differences were observed in the return rates for ANC and family planning services between the intervention and control groups (Adjusted odds ratios close to 1)	The results indicate that SMS reminders can enhance adherence to vaccination schedules, though their effectiveness may differ across health services, likely influenced by recipients' perceived urgency or importance of the service [25].

4 Discussion

The findings underscore the potential of SMS-based interventions to enhance ANC attendance, maternal health knowledge, and service utilisation in LMICs. Across the studies reviewed, SMS interventions demonstrated varying degrees of effectiveness (see Table 4), reflecting diversity in implementation approaches, population contexts, and healthcare systems.

Several studies have been conducted, including [12,20], highlighted substantial improvements in ANC attendance and skilled delivery rates, with odds ratios and effect sizes indicating robust effects. These findings suggest that SMS reminders and educational messages can effectively address common barriers to maternal healthcare, such as a lack of awareness or forgetfulness. However, the mixed outcomes observed in some studies, such as [22] who reported a limited impact on ANC visits despite significant improvements in skilled delivery and facility-based births, indicate the need for context-specific tailoring of the message content and delivery frequency.

The review highlights the strong influence of SMS-based interventions on maternal health knowledge and birth preparedness. For instance, Masoi & Kibusi [9] reported large effect sizes in knowledge about obstetric and newborn danger signs, while Batool et al. [19] emphasised knowledge gains despite limited impact on follow-up visits. These findings underscore the importance of well-designed content that resonates with the educational needs and cultural contexts of the target population. Effective interventions appear to combine timely reminders with actionable health education, reinforcing preparedness, and engagement.

Participant satisfaction was consistently high across studies, such as Alhaidari et al. [18] and Oliveira-Ciabati et al. [24], where users expressed positive feedback about the usability and relevance of SMS interventions. High engagement levels, including two-way communication and interactive features, were associated with better adherence to health recommendations. These results suggest that user-centred design and feedback mechanisms are critical to the success and sustainability of SMS interventions. However, interactive features in some cases might not be ideal in low resource settings as it implies the use of advanced technologies (smartphones) that are not necessarily accessible to the targeted women.

Despite these positive findings, this review also revealed limitations in the effectiveness of SMS interventions. For instance, Kawakatsu et al. [25] reported variability in effectiveness across different health services, such as higher adherence to vaccination schedules but no significant improvement in ANC or family planning return rates. Others [19] identified logistical barriers and social norms as factors limiting follow-up visits. These mixed outcomes emphasise the need for comprehensive program designs that account for broader systemic and sociocultural factors influencing maternal health behaviours.

Limitations and future research

Our study acknowledges several limitations that may influence the generalisability and applicability of the findings. The systematic review process was conducted by a single reviewer, which, despite ensuring a consistent review approach, could introduce bias and limit the breadth of interpretation typically enriched by multi-reviewer analysis. This approach was necessitated by resource constraints and the availability of subject matter experts with the required language proficiency. To mitigate potential bias, rigorous adherence to predefined inclusion and exclusion criteria was maintained throughout the review process. Although not optimal, this approach was necessary to ensure the feasibility of the study within the available resources. Moreover, given that this study is focused solely on a systematic review, as stated, we did not conduct quantitative statistical analyses typically required for meta-analysis, such as pooled effect size calculations or heterogeneity tests (e.g. prediction Intervals, or I^2 (proportion of variance))[35]. While these methods could have added quantitative depth, they were not necessary to achieve the primary objective of synthesising and qualitatively analysing the evidence to inform our research focus. This methodological void should be addressed in future studies.

The findings highlight several trends, with important implications for future research and implementation. The dominance of East Africa and RCTs reflects a mature research landscape in this region and study design; however, the underrepresentation of other regions and the lack of diverse study methodologies suggest gaps that need to be addressed. Furthermore, the consistent effectiveness of mixed interventions indicates that tailoring SMS-based approaches to combine education and reminders can yield optimal outcomes. Based on these findings,

several practical recommendations can be proposed. First, it is crucial to tailor the content of SMS messages to the cultural and educational background of the target population to enhance engagement and comprehension. Additionally, integrating feedback mechanisms within SMS platforms can provide valuable insights into the effectiveness of interventions and areas of improvement. Healthcare providers and policymakers should consider establishing partnerships with local telecommunications providers to leverage existing infrastructure and ensure the sustainability of interventions, helping to refine or replicate these interventions and explore their long-term impact on maternal and child health outcomes. Moreover, ongoing training and support for healthcare staff involved in deploying these interventions are essential to maintaining the quality and consistency of care provided through SMS. These recommendations aim to optimise the impact of SMS-based interventions on maternal health outcomes, making them a viable component of prenatal care strategies in low-resource settings.

5 Conclusion

This review shows that mobile health interventions hold significant promise for improving maternal health outcomes, particularly in low-and middle-income countries (see eFig. 8). The interventions demonstrated positive effects on ANC attendance, health knowledge, and general maternal health behaviours, underscoring the value of digital health tools in resource-limited settings. However, the effectiveness of these interventions varied widely and was influenced by factors such as the content and frequency of messages, and the implementation tools used. Continued efforts in this field can significantly reduce barriers to antenatal care and improve maternal and child health outcomes.

6 Declaration of competing interest

The authors have no conflicts of interest to declare relevant to this paper's content.

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9 Declaration of generative AI and AI-assisted technologies in the writing process

While preparing this work, the authors used GPT 4 and 4o to improve readability and language. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

10 Data availability statement

All data relevant to the study are included in the article or are uploaded as supplementary information. Extracted data, both raw and coded, are available upon reasonable request from the corresponding author.

11 Ethics statements

11.1 Patient consent for publication

Not applicable.

11.2 Ethics approval

This study did not involve human participants. Ethical approval was not required for this systematic review because all the data were obtained from published articles.

12 Authors' contribution

MK: Project administration, conceptualisation, methodology, writing original draft preparation, data curation, formal analysis after paper selection. MM: Conceptualisation, writing-reviewing, editing and supervision. All the authors approved the final manuscript. The corresponding author (MK), as guarantor, accepts full responsibility for the finished article, has access to all data, and controlled the decision to publish.

13 Figure legends

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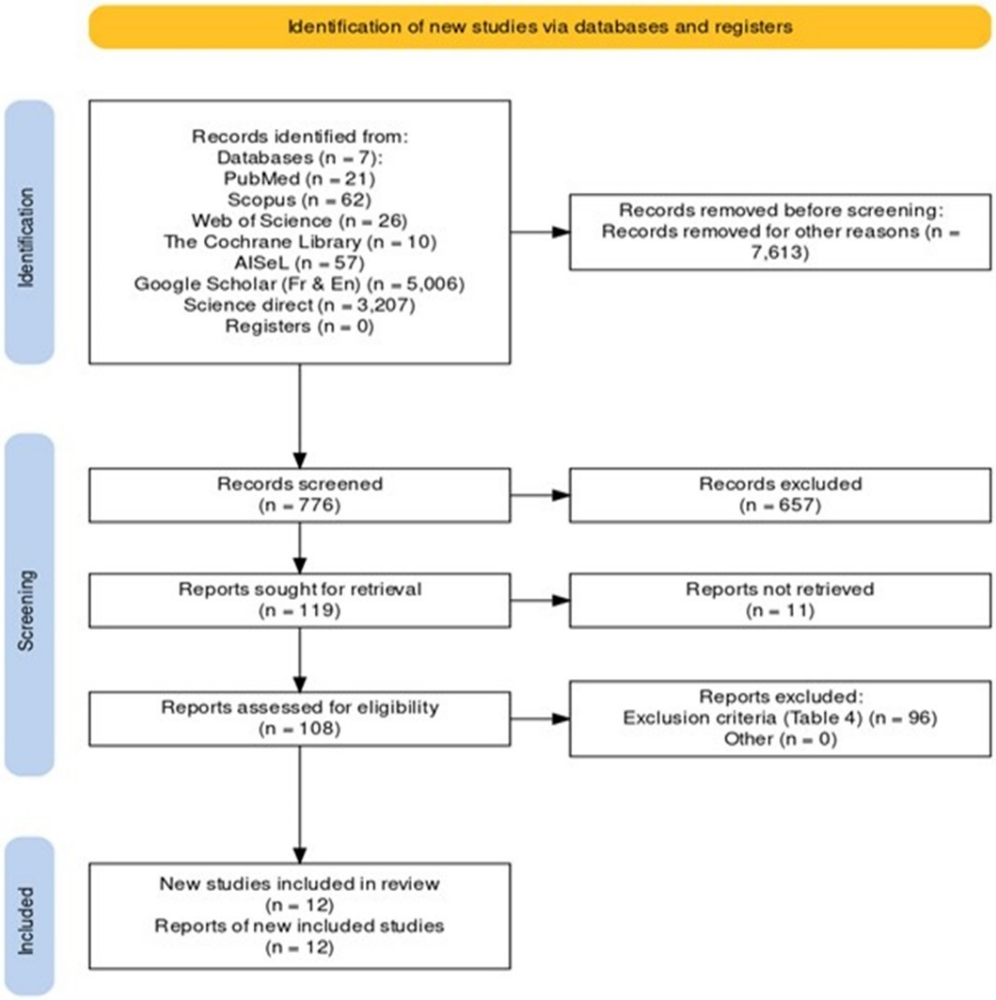
15 Appendix

(See attached checklist file)



Flow Diagram of the search

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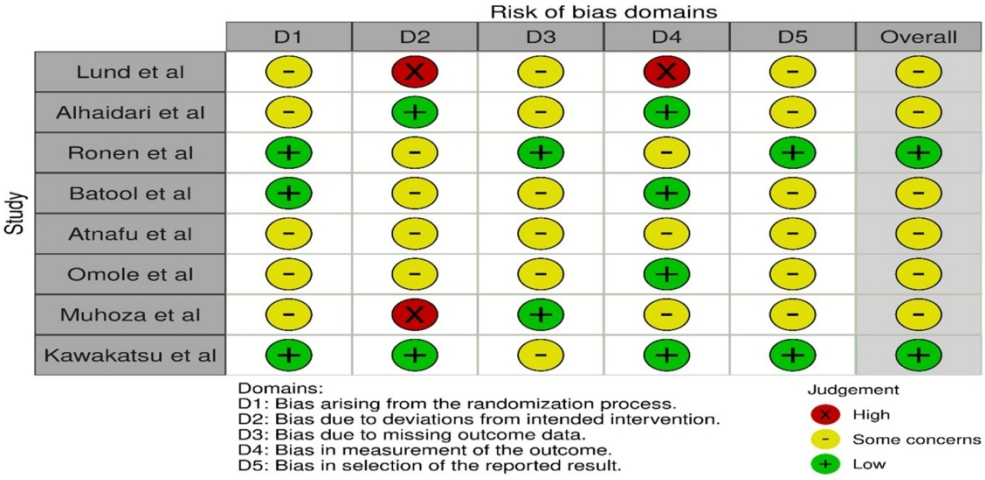

Traffic-light plot ROB2

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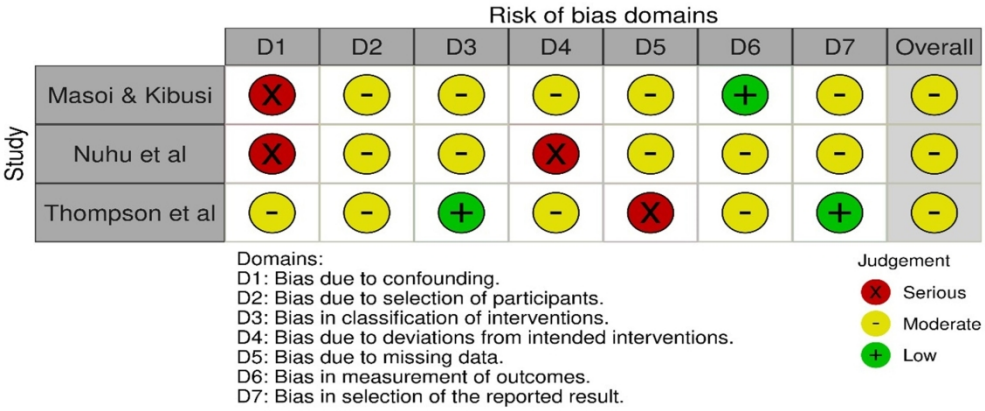

Trafic-light plot ROBINS-I

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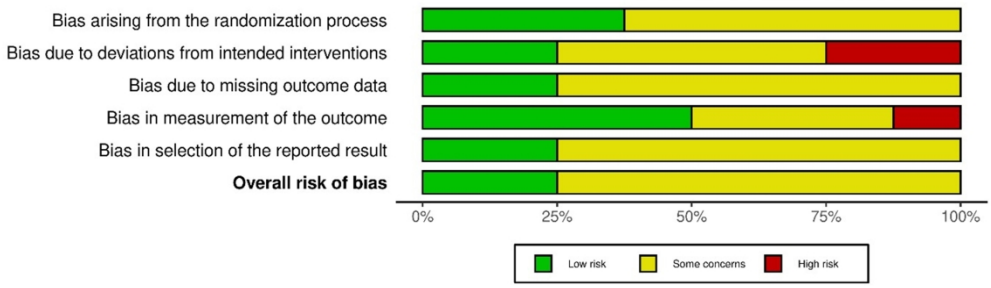

Summary plot ROB2

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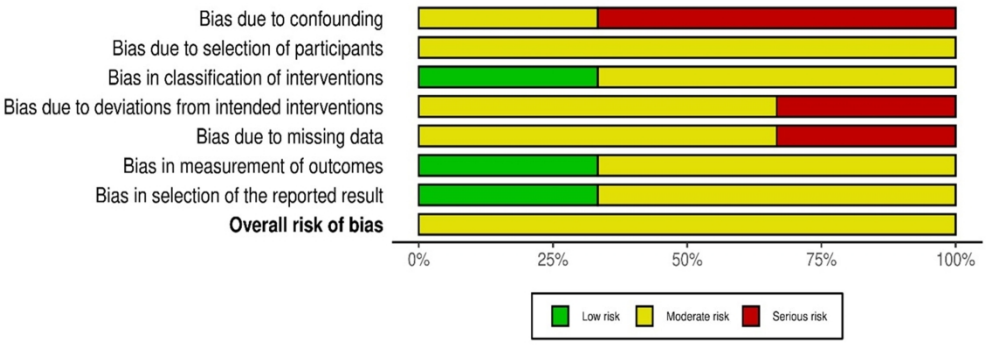

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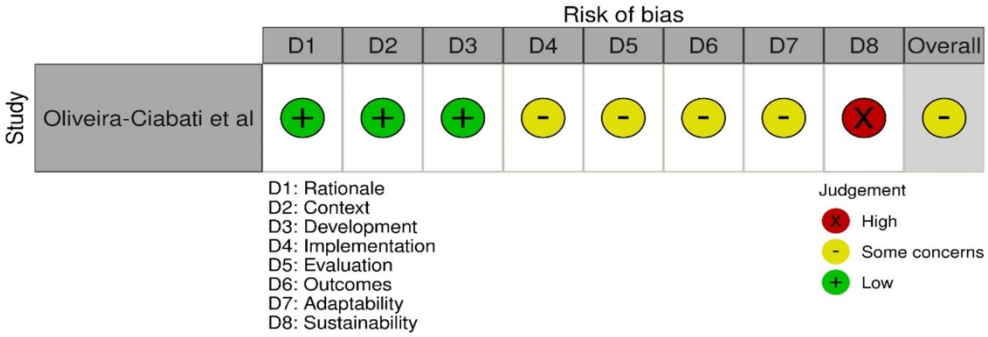

Traffic-light plot Checklist for reporting development

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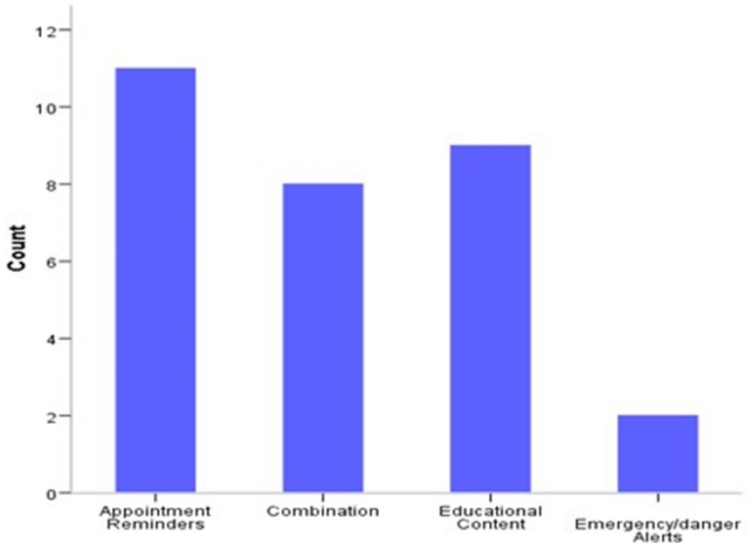

Content of SMS

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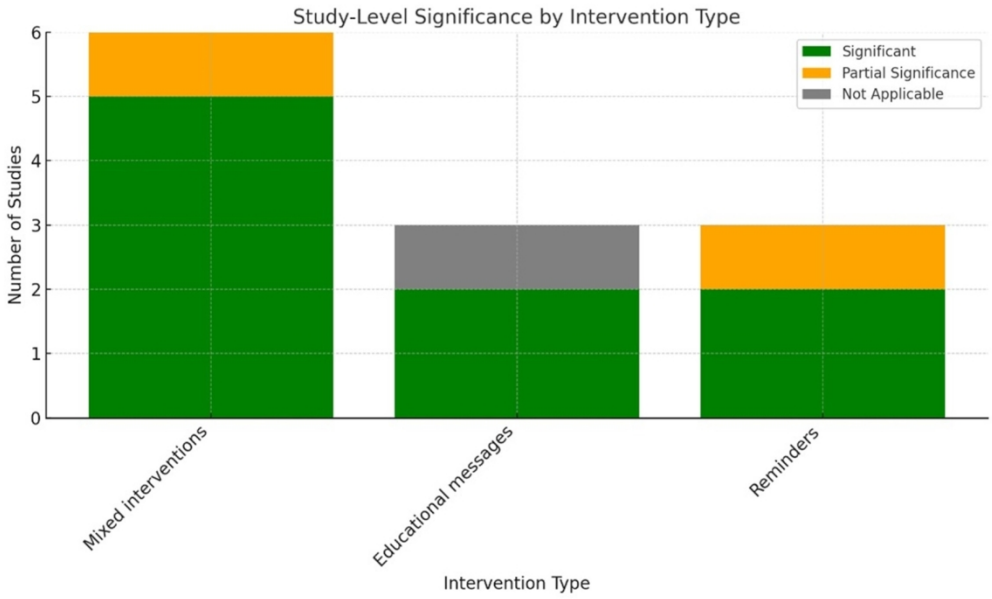

Effectiveness of intervention types

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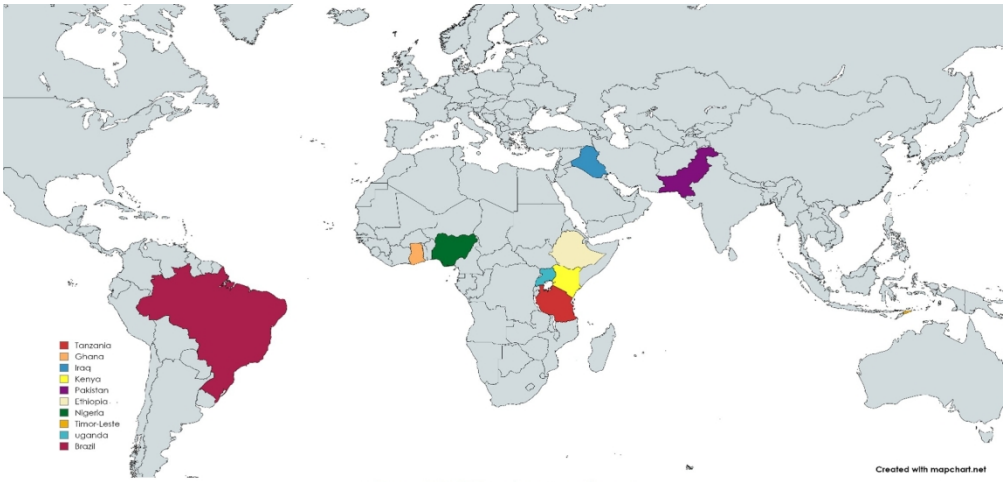


eFigure 8 SMS-Based apps on the map

SMS-Based apps on the map

193x99mm (300 x 300 DPI)

Supplementary tables and figures

eTable 1 Full search strategy

	PubMed	Scopus	Web of Science	The Cochrane Library	**AISeL**	**Google Scholar**	**Science Direct**
Search done in	Title and Abstract	Title, Abstract and Keywords	Abstract	Title, Abstract and Keywords	All fields	All fields	All fields
Language	English					English and french	English
Year filter	2014-2024						
English search strings	("SMS-based applications" OR "text messaging" OR "mobile health" OR "mHealth") AND ("antenatal care" OR "prenatal care" OR "pregnancy care" OR "ANC") AND ("developing countries" OR "low-income countries" OR "resource-limited settings")						
French search string	("applications basées sur SMS" OU "messagerie texte" OU "santé mobile" OU "mSanté") ET ("soins prénatals" OU "soins anténataux" OU "soins pendant la grossesse" OU "CPN") ET ("pays en développement" OU "pays à faible revenu" OU "contextes à ressources limitées")						

eTable 2. Summary of search results

	PubMed	Scopus	Web of Science	The Cochrane Library	**AISeL**	**Google Scholar**		**Science Direct**	**Total**
Results (considered)	21	62	26	10	57	En	Fr	3207(200)	776
						4750 (200)	256(200)		
Suitable studies	3	1	0	0	1	5	0	2	12

eTable 3 Inclusion and exclusion criteria

Description	**Inclusion**	**Inclusion justification**	**Exclusion**	**Exclusion justification**
Study Design	Randomised controlled trials (RCTs), quasi-experimental, observational, and	Allows for a comprehensive understanding of different aspects of SMS-based	Editorials, opinion pieces, reviews, and studies without primary data or clear outcomes	They do not provide empirical data necessary for a

	qualitative studies that provide data on the implementation, usage, and outcomes of SMS-based antenatal care interventions.	interventions from efficacy to real-world application and user experiences	related to antenatal care and SMS-based interventions.	systematic review
Population	Studies involving pregnant women in developing countries. This can include women of all ages, ethnicities, and stages of pregnancy.	To ensure that the findings are relevant to populations where SMS-based interventions might be most necessary and effective due to limited healthcare access.	Studies focusing on populations outside of developing countries or on non-pregnant women.	To maintain the review's focus on the specific needs and context of pregnant women in resource-limited settings.
Intervention	Studies that focus on SMS-based applications designed to improve antenatal care information and attendance. That includes interventions promoting health education, appointment reminders, health monitoring, and support through text messaging.	To evaluate the effectiveness of this technology in enhancing ANC.	Studies that do not specifically use SMS-based communication as a primary method for delivering antenatal care information or support.	To ensure that the results are specific to the impact of SMS-based interventions without the confounding effects of other communication technologies.
Comparators	Studies with or without a control group. For those with a control group, the comparison can be standard care, no intervention, or other digital health interventions not using SMS.	To allow for a broader range of data on the effectiveness of SMS interventions, including comparative analyses against different forms of care.	Studies where the control group is subjected to interventions primarily based on SMS technology; studies that do not clearly describe the comparator.	To clearly distinguish the effect of SMS interventions from other variables.

Outcomes	Studies that measure outcomes related to antenatal care include improvements in antenatal care attendance, enhanced knowledge of antenatal health, improved pregnancy outcomes, and user satisfaction with the SMS service.	ensures that the review directly addresses the impact of SMS interventions on key health metrics and patient satisfaction.	Studies that do not report specific outcomes related to antenatal care	To maintain clarity and relevance.
Publication date	Studies published within the last ten years, from the year 2014	To ensure that the data reflects recent advancements in SMS technology and contemporary healthcare contexts.	Studies published more than ten years ago.	To avoid data that may not accurately reflect current technologies or healthcare practices.
Language	Content written in English or French	To expand the scope of the literature reviewed and due to language capabilities.	Content not written in English or French	To ensure quality due to language proficiency constraints.

eTable 4 Data extraction form

Item	Value
Study Identification	
Study ID	Identification
Author name	Name(s) of the author(s)
Title	Title of the paper
Journal	Journal where the paper is published
Year	Year of publication
Study design	randomised controlled trial, observational study, etc
Country	The country where the study was conducted
Study Participants	
Population description	Accurate description of the population
Sample size	value
Inclusion criteria	Main criteria reported

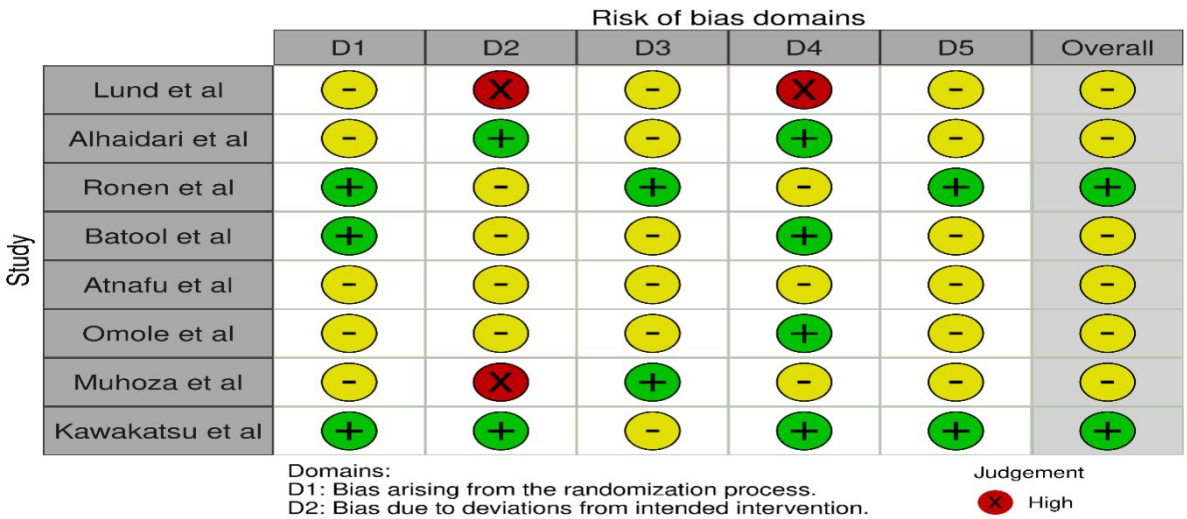
Exclusion criteria	Main criteria reported
Intervention Details	
Description of the SMS-based application	General description with purpose
Content of the SMS-based application	Content of the messages
Message sending frequency of the app	frequency of messages
Tools employed for the implementation of the app	Resources and tools employed for the implementation and/or requirements
Duration of the intervention	Duration as reported
Control or comparator interventions	As reported, if applicable
Outcomes	
Primary outcomes	Improve antenatal care attendance, knowledge enhancement, vaccination visits, satisfaction, etc.
Secondary outcomes	As reported, if applicable
Outcome measurement tools and methods	As reported
Results	
Key findings	Summary of results related to primary and secondary outcomes
Statistical significance	If applicable
Limitations	Limitations reported by the study
Quality Assessment	
Risk of bias assessment	For each study, depending on the study design

*Table 5 Study design * Primary outcome*

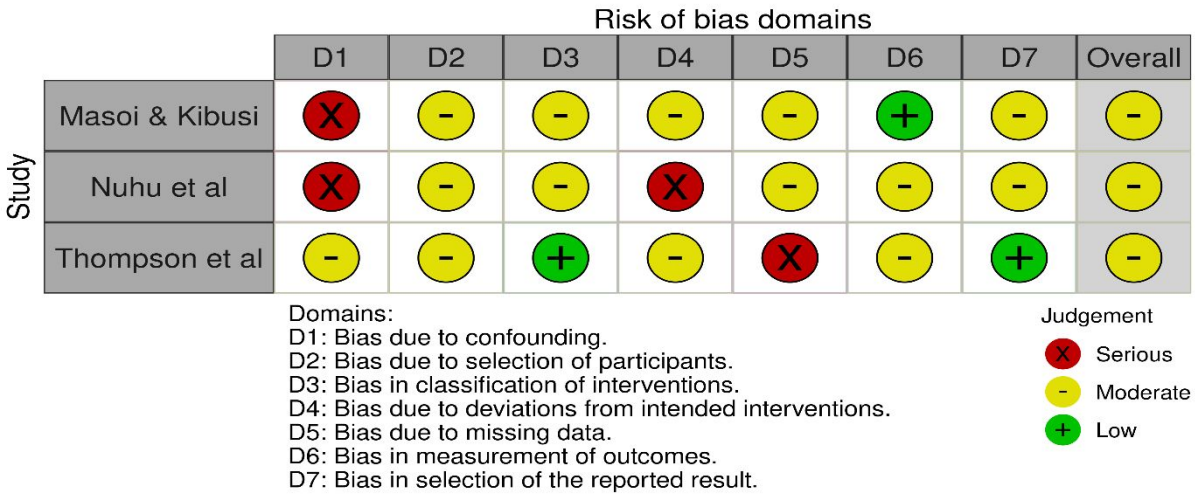
		Primary outcome							Total
		Improved Attendance	Increased Knowledge	skilled delivery attendance	Neonatal mortality	Reduced Complications	patient satisfaction	Others	
Study design	RCT	7	1	2	1	0	1	1	8
	Non-RCT	2	1	2	0	1	0	1	3
	Other	0	1	0	0	0	0	1	1
Total		9	3	4	1	1	1	3	12

eTable 6. Impact of study design

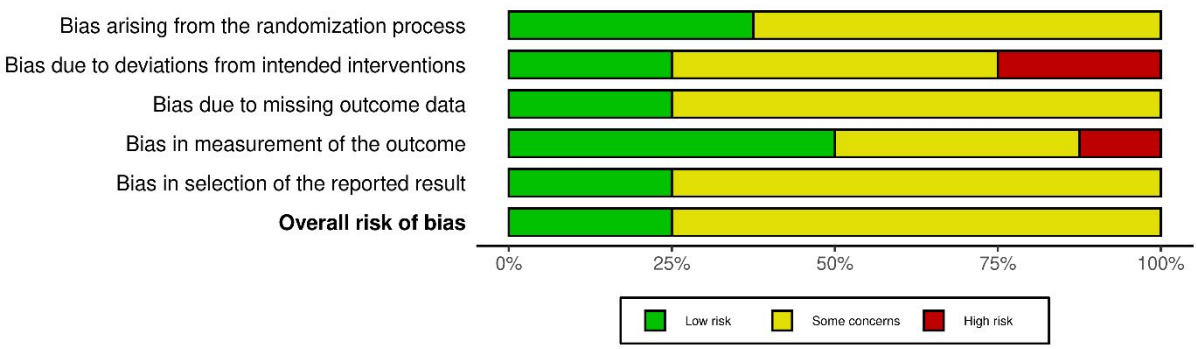
Study Design	Total	Significant_Studies	Partial_Significant_Studies	Not Applicable_Studies	Regions covered
RCT	8	5	2	1	Ethiopia, Kenya, Nigeria, Pakistan, Tanzania, Uganda, Iraq
QE	3	3	0	0	Ghana, Tanzania, Timor-Leste
Sociotechnical approach using the prototype method.	1	1	0	0	Brazil



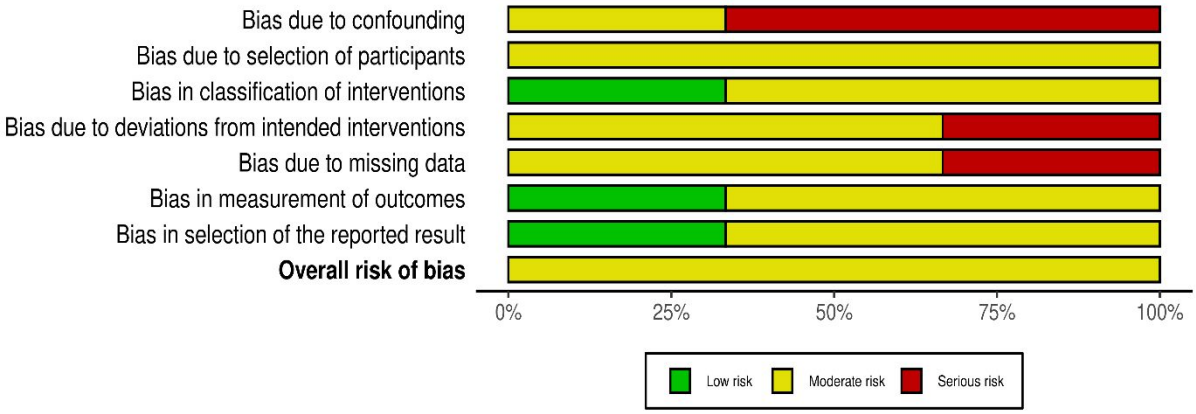
eFigure 1 Traffic-light plot ROB2



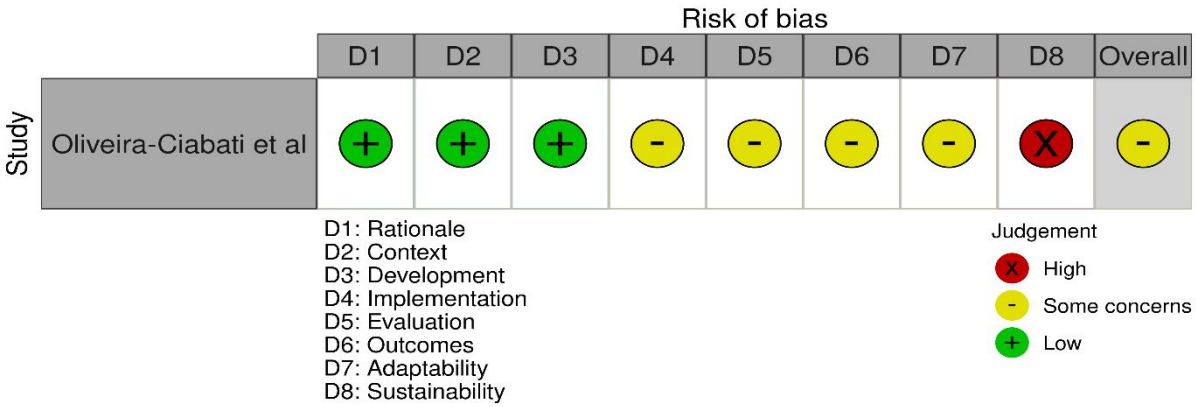
eFigure 2 Trafic-light plot ROBINS-I



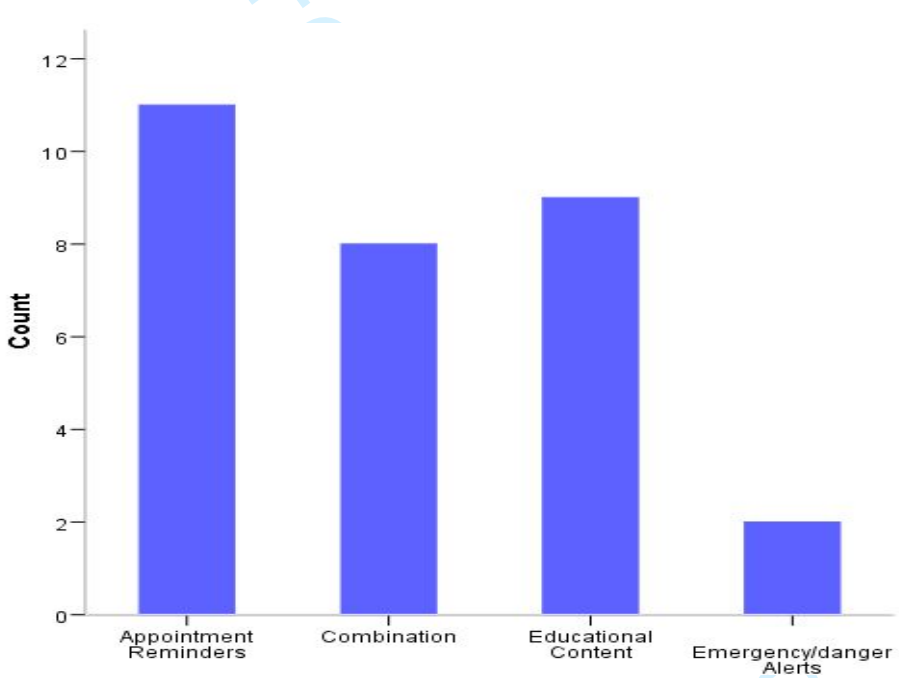
eFigure 3 Summary plot ROB2.



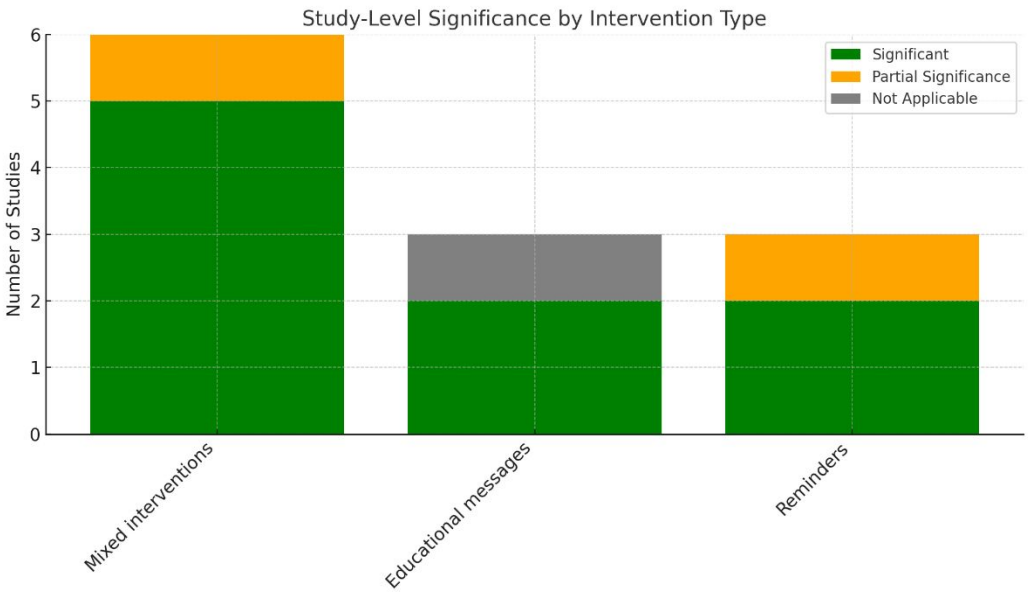
eFigure 4 Summary Plot ROBINS-I



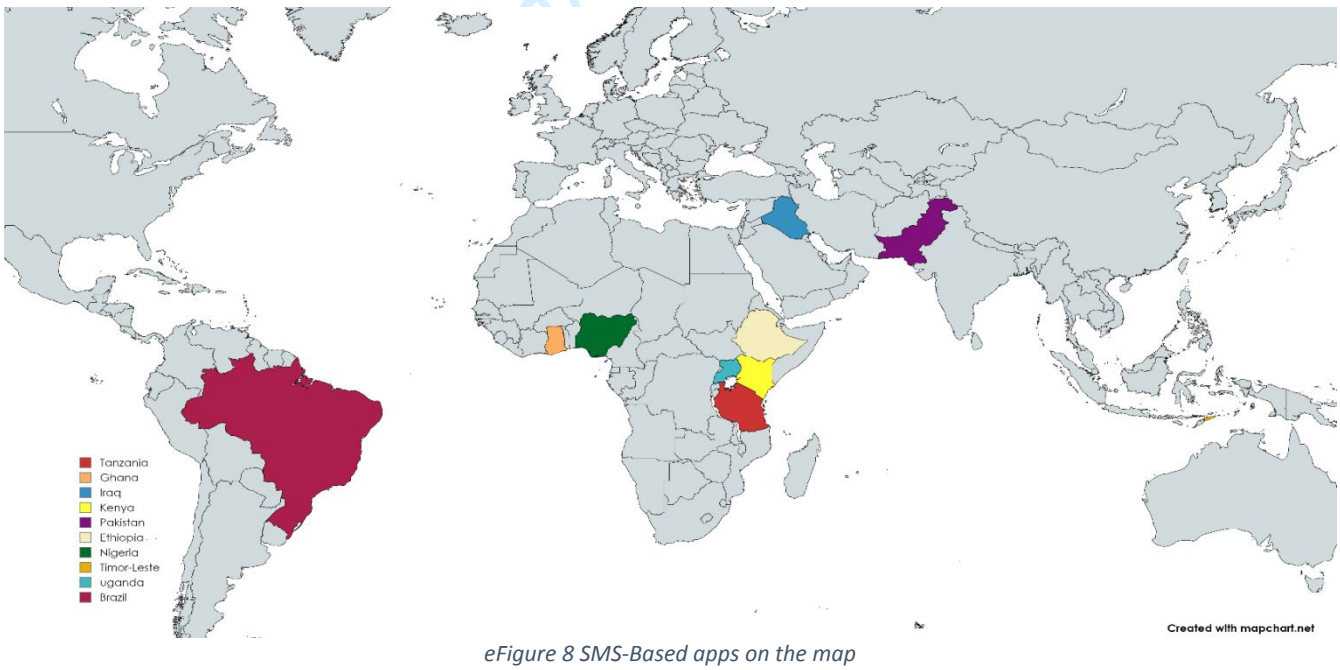
eFigure 5 Traffic-light plot Checklist for reporting development.



eFigure 6 Content of SMS



eFigure 7 Effectiveness of intervention types



eFigure 8 SMS-Based apps on the map

eFigure legends

eFigure1: Traffic-light plot ROB2

eFigure2: Trafic-light plot ROBINS-I

eFigure3: Summary plot ROB2.

eFigure4: Summary Plot ROBINS-I

eFigure5: Traffic-light plot Checklist for reporting development.

eFigure6: Content of SMS

eFigure7: Effectiveness of intervention types

eFigure8: SMS-Based apps on the map

PRISMA 2020 for Abstracts Checklist

Section and Topic	Item #	Checklist item	Reported (Yes/No)
TITLE			
Title	1	Identify the report as a systematic review.	Yes
BACKGROUND			
Objectives	2	Provide an explicit statement of the main objective(s) or question(s) the review addresses.	Yes
METHODS			
Eligibility criteria	3	Specify the inclusion and exclusion criteria for the review.	Yes
Information sources	4	Specify the information sources (e.g. databases, registers) used to identify studies and the date when each was last searched.	Yes
Risk of bias	5	Specify the methods used to assess risk of bias in the included studies.	Yes
Synthesis of results	6	Specify the methods used to present and synthesise results.	Yes
RESULTS			
Included studies	7	Give the total number of included studies and participants and summarise relevant characteristics of studies.	Yes
Synthesis of results	8	Present results for main outcomes, preferably indicating the number of included studies and participants for each. If meta-analysis was done, report the summary estimate and confidence/credible interval. If comparing groups, indicate the direction of the effect (i.e. which group is favoured).	Yes
DISCUSSION			
Limitations of evidence	9	Provide a brief summary of the limitations of the evidence included in the review (e.g. study risk of bias, inconsistency and imprecision).	Yes
Interpretation	10	Provide a general interpretation of the results and important implications.	Yes
OTHER			
Funding	11	Specify the primary source of funding for the review.	Yes
Registration	12	Provide the register name and registration number.	N/A

PRISMA 2020 CHECKLIST

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Title, page 1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Abstract, page 1
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	page 2-3
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Page 4
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Page 4-5
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Page 4
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Page 4
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Page 4-5
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Page 6, page 17-18
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Page 6
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Page 6
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Page 6
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	NA
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Page 4-5
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	NA
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	NA
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	NA

Section and Topic	Item #	Checklist item	Location where item is reported
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	Page 14
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	NA
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	NA
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	NA
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Page 5
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Page 5
Study characteristics	17	Cite each included study and present its characteristics.	Page 7-8
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Page 6
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimates and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Page 15-16
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Page 6
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	NA
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	NA
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	NA
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	Page 6
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	NA
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Page 17
	23b	Discuss any limitations of the evidence included in the review.	Page 17-18
	23c	Discuss any limitations of the review processes used.	Page 17-18
	23d	Discuss implications of the results for practice, policy, and future research.	Page 17-18
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	NA
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	NA
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	NA

Section and Topic	Item #	Checklist item	Location where item is reported
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Page 19
Competing interests	26	Declare any competing interests of review authors.	Page 18
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Page 19

BMJ Open

Effectiveness of SMS-Based interventions in enhancing antenatal care in developing countries: systematic review

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Secondary Subject Heading:	Health informatics, Public health, Sociology, Reproductive medicine
Keywords:	Health informatics < BIOTECHNOLOGY & BIOINFORMATICS, Information technology < BIOTECHNOLOGY & BIOINFORMATICS, Pregnant Women, PUBLIC HEALTH

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Effectiveness of SMS-Based interventions in enhancing antenatal care in developing countries: systematic review

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Abstract

Objectives: Pregnant women in low- and middle-income countries (LMICs), including Mali, often face challenges such as limited access to comprehensive health information and services. Mobile health (mHealth) interventions, particularly SMS-based interventions, have shown promise in addressing maternal health challenges. This review aims to provide an overview of existing SMS-based antenatal care (ANC) applications and assess their effectiveness in improving maternal and child health outcomes.

Design: A systematic literature review was conducted based on updated PRISMA 2020 guidelines.

Data sources: PubMed, Scopus, Web of Science, Cochrane Library, Association for Information Systems eLibrary, Direct Science, and Google Scholar were searched through 25 March 2024.

Eligibility criteria: Studies that focused on SMS-based interventions designed to improve antenatal care information and attendance, published in English or French, conducted in LMICs, and published between 2014 and 2024 were included. Exclusion criteria eliminated Studies that did not report primary outcomes or did not directly involve SMS-based interventions for ANC.

Data extraction and synthesis: Followed predefined criteria, and the risk of bias was assessed using the Cochrane risk-of-bias tool for randomised trials (RoB 2), the Risk Of Bias In Non-randomised Studies-of Interventions (ROBINS-I), and the Checklist for Reporting the Development and Evaluation of Complex Interventions in Healthcare (CReDECI), depending on study design. A subgroup analysis was performed to explore variations in outcomes by region and study design.

Results: The review identified a range of SMS-based interventions (N=12) that differed in target audience, message frequency (weekly, pregnancy stage-oriented), and content (reminders (91.7% of cases, 11/12), educational (75%), and danger signs (16.7%)). Regional analysis highlighted significant research activity in East Africa but with mixed significance levels. Study design analysis revealed that randomised controlled trials (RCTs) yielded the most significant

results, with 5 of 8 studies showing full significance, whereas quasi-experimental studies demonstrated consistent but less frequent effectiveness. Implementation tools varied from SMS gateways to custom applications and third-party platforms, with some interventions combining these approaches. SMS interventions positively impacted ANC attendance, maternal health knowledge, and behaviours, with effectiveness varying based on the intervention type, content, frequency, and implementation approach.

Conclusion: SMS-based interventions have the potential to enhance ANC in LMICs by providing tailored health information and promoting healthy behaviours. Further research should focus on refining or replicating these interventions and exploring their long-term effects on maternal and child health outcomes, particularly in underrepresented regions.

Keywords: Antenatal Care, ANC, mHealth, SMS-Based intervention, LMICs

Strengths and limitations of this study

- This review utilised the PRISMA 2020 guidelines, ensuring a thorough and standardised approach to conducting the systematic review, thereby enhancing the transparency and reproducibility of the research process.
- The risk of bias in the included studies was meticulously assessed using three robust tools: RoB 2, ROBINS-I, and the CReDECI.
- Data extraction and synthesis followed predefined criteria to enhance the consistency and reliability.
- A notable limitation is that only one reviewer assessed the included papers.
- Quantitative statistical analysis typically performed in meta-analyses, such as pooled effect size calculation, was not undertaken, as the study was limited to a systematic review to inform our research focus.

1 Introduction

The lack of comprehensive health information and services for pregnant women is a significant challenge in improving maternal and child health in Mali and similar settings. Literature reports that knowledge of the place of consultation, treatment costs, pregnancy complications, and the place of antenatal care treatment influence maternal mortality [1]. Additionally, regarding services, births attended by skilled health personnel correlate with maternal mortality in sub-Saharan Africa [2]. Poor antenatal and maternal health awareness among pregnant women contributes to inadequate health behaviours and care-seeking, causing avoidable morbidity and mortality.

Antenatal care (ANC) is a critical component of maternal healthcare that aims to monitor and enhance the health outcomes of pregnant women and their unborn children. Regular ANC visits enable healthcare providers to detect and manage potential health problems, educate women about pregnancy and childbirth, and advocate for healthy behaviours that benefit both the mother and the child [3–5]. Despite the global recognition of ANC's importance, significant challenges persist in ensuring comprehensive care for all pregnant women, particularly in low- and middle-income countries (LMICs). Studies have shown that maternal education, household income, and cultural beliefs significantly affect the utilisation of ANC services, with disparities in access and use across different socioeconomic and demographic groups [5,6]. Addressing

these challenges requires targeted interventions to improve the access, awareness, and affordability of ANC services for pregnant women in these regions.

The rapid growth of mobile technology has led to innovative ways of increasing healthcare access and engaging patients. SMS-based systems have become vital for closing information gaps and boosting engagement with ANC services. These applications offer a platform for delivering timely, relevant information directly to the mobile phones of pregnant women, thus increasing awareness of the importance of ANC, reminding women of their upcoming appointments, and providing crucial health-related guidance [7–12]. Studies have demonstrated the potential of mobile health (mHealth) interventions to monitor prenatal care among pregnant women in LMICs [13] and have evaluated the effectiveness of SMS on focused ANC visits and skilled birth attendance in such settings [7].

For instance, a meta-analysis found that mHealth interventions improved the uptake of 4 or more ANC visits among pregnant women in LMICs, with both one-way and two-way communication methods showing positive effects [14]. SMS support during pregnancy was also associated with a decreased risk of perinatal death compared to routine prenatal care in one study [15]. Interestingly, while SMS interventions generally improved ANC utilisation, their impact varied across contexts. In settings where facility delivery rates were already high, SMS interventions showed unclear effects. However, in areas with lower facility delivery rates, these interventions significantly increase facility-based deliveries [14].

Despite rapid advancements in mobile health technologies, basic SMS remains a cornerstone in regions where limited internet access and low smartphone penetration hinder the adoption of complex systems. This review addresses the utility and effectiveness of SMS-based interventions in settings in which basic utilities such as electricity or the Internet may be unreliable. By exploring the impact of SMS-based applications on metrics such as ANC visit attendance and skilled delivery attendance, we aim to illuminate the potential of digital interventions to complement traditional ANC services and contribute to reducing maternal and neonatal morbidity and mortality, supporting public health goals [16], and contributing to the broader global health narrative of health, sustainability, and transformation [17].

The remainder of this paper is organised as follows. The second section details the methodology by describing the research question, data sources, search strategy, selection criteria, and data extraction process. It also presents the analysis tools, data characteristics, and risk-of-bias assessment. The third section presents the results, which are discussed in section four along with limitations. Section five concludes the paper.

2 Methodology

A systematic approach was employed to identify and evaluate significant findings concerning the use of SMS-based interventions to improve ANC in developing countries, as documented in peer-reviewed online French and English journals over the past decade. To ensure a thorough and effective review process, we followed the updated guidelines outlined in the 2020 edition of the Preferred Reporting Items for Systematic reviews and Meta-Analyses [18]. The PRISMA 2020 Abstracts and Checklist items can be accessed from the appendix. The review process,

including screening, quality assessment, and data extraction, was conducted by a single reviewer due to resource constraints and the need for language proficiency. To minimise potential bias, predefined inclusion and exclusion criteria were strictly followed, and standardised tools, such as RoB 2, ROBINS-I, and ROBVIS, were applied to ensure methodological rigor.

2.1 Research questions

The objectives of this study were to address the following research questions:

RQ1: What are the characteristics and availability of SMS-based applications developed between 2014 and 2024 to enhance ANC information and attendance among pregnant women in low and middle-income countries?

RQ2: How effective are these SMS-based applications in improving antenatal care information and attendance among pregnant women in low- and middle-income countries compared to usual care?

2.2 Data sources

The search included the following electronic databases or search engines: PubMed (last searched 19 March 2024), Scopus (last searched 21 March 2024), Web of Science (last searched 22 March 2024), Cochrane Library (last searched 20 March 2024), Association for Information Systems eLibrary (AISeL) (last searched 20 March 2024), Direct Science (last searched 21 March 2024), and Google Scholar (last searched 25 March 2024). These searches were conducted to ensure the inclusion of the most up-to-date and relevant literature.

2.3 Search strategy

The formulated research questions guided the construction of the search strings, leading to their combination through logical connectors. The resulting string was [("SMS-based applications" OR "text messaging" OR "mobile health" OR "mHealth") AND ("antenatal care" OR "prenatal care" OR "pregnancy care" OR "ANC") AND ("developing countries" OR "low-income countries" OR "resource-limited settings")]. This process was adapted according to the requirements of each electronic database. Science Direct, for example, did not accept more than eight logical connectors in a single search. The author translated the search string into French by combining words and expressions used in the English search. The resulting string was *("applications basées sur SMS" OU "messagerie texte" OU "santé mobile" OU "mSanté") ET ("soins prénatals" OU "soins anténataux" OU "soins pendant la grossesse" OU "CPN") ET ("pays en développement" OU "pays à faible revenu" OU "contextes à ressources limitées")*. The process used for searching and selecting different publications is summarised in a Diagram Flow and presented in Fig. 1. The flow diagram of the search was created using the R-developed online tool by Haddaway et al. [19]. eTable 1 in the supplementary files summarises the full search strategy, and eTable 2 details the results per database.

2.4 Selection criteria

Initially, 776 publications were found, as detailed in eTable 2. Additional inclusion and exclusion criteria were applied to shift the initial findings to pinpoint studies pertinent to our

goals. Consequently, these publications underwent a rigorous screening process based on the inclusion and exclusion criteria. These criteria were defined to ensure the relevance and quality of the analysed data. The study design criteria included randomised controlled trials (RCTs), quasi-experimental, observational, and qualitative studies that provided data on the implementation, usage, and outcomes of SMS-based ANC interventions. Editorials, reviews, opinion pieces, and studies lacking primary data or clear outcomes related to ANC and SMS-based interventions were excluded.

The population criteria focused on studies involving pregnant women in LMICs encompassing women of all ages, ethnicities, and stages of pregnancy. For the intervention criteria, the studies needed to focus on SMS-based systems designed to improve ANC information and attendance. These included interventions promoting health education, appointment reminders, health monitoring, and support through text messaging. Studies that did not specifically use SMS-based communication as the primary method for delivering ANC information or support were excluded. Criteria such as comparators, outcomes, publication dates, and languages were also used. eTable 3 in the supplementary files provides a detailed description of the inclusion and exclusion criteria, along with the rationale for each criterion. In the subsequent phase, the process involved verifying the presence of duplicate papers given that multiple databases were used for the search. This resulted in identifying and removing 11 duplicate documents from the dataset. Full texts of papers were then retrieved and checked. Following this meticulous selection phase, a final count of 12 papers was deemed appropriate and suitable for review (Fig.1).

2.5 Data extraction

After completing the selection process, we extracted information from the selected papers. The study identification items included author names, paper title, journal, publication year, study design type, and the country where the study was conducted. Details regarding the study participants were also extracted, including an accurate description of the study population, sample size, and primary inclusion and exclusion criteria. Information on the intervention details extracted includes a description and purpose of the SMS-based application as presented in the paper, the content of messages, frequency of sending, resources and tools for implementation, and intervention duration. Additionally, control or comparator interventions were retrieved as reported, if applicable. The reported outcomes (primary and secondary) were then extracted. Key findings related to the indicated outcomes, statistical significance where applicable, and any reported limitations were also extracted. The complete data extraction form is provided in the supplementary eTable 4.

2.6 Tools and analysis

The data set was managed using the open-source desktop-based application Mendeley version 1.19.8. The extracted items were stored and used to generate descriptive statistics using JabRef (version 5.13), Microsoft 365 Excel (version 2403), and IBM SPSS Statistics 20.

2.7 Patient and public involvement

None.

2.8 Data characteristics

A bibliometric overview of the selected papers is described in Table 1. Each paper was assigned a numerical identifier and categorised according to the year of publication, from oldest to most recent and by source.

2.9 Risk of Bias Assessment

In this study, the dataset comprised of 12 scholarly articles. Each article was evaluated for potential bias, with assessment criteria varying according to the study design. Three distinct tools were utilised to conduct this assessment: version 2 of the Cochrane Risk-of-Bias tool for randomised trials (RoB 2) [20] was applied to eight studies, the Risk Of Bias In Non-randomised Studies - of Interventions (ROBINS-I) tool [21] to three studies, and the Checklist for Reporting the Development and Evaluation of Complex Interventions in Healthcare [22] was conveniently used for one study. Visual representations of the assessments, including traffic light plots (see eFig. 1 and 2) and summary plots (see eFig. 3 and 4), were created for the two groups (RoB 2 and ROBINS-I). Refer to eFig. 5 to assessment of the study using the checklist. These plots were generated using the Risk Of Bias VISualisation (ROBVIS) tool [23]. The overall risk assessment for the papers was categorised as "some concerns". Consequently, we did not exclude any of the documents included due to the absence of many significant high/critical issues with individual papers.

Table 1 Bibliometric overview

ID	Author(s)	Title	Journal/Conf	Country (region)	Year	Source
01	Lund et al [12]	Mobile Phone Intervention Reduces Perinatal Mortality in Zanzibar: Secondary Outcomes of a Cluster Randomized Controlled Trial	JMIR mhealth and uhealth	Tanzania (Zanzibar)	2014	PubMed
02	Masoi & Kibusi [9]	Improving pregnant women's knowledge on danger signs and birth preparedness practices using an interactive mobile messaging alert system in Dodoma region, Tanzania: a controlled quasi-experimental study	Reproductive Health	Tanzania (Dodoma)	2019	
03	Nuhu et al [8]	Impact of mobile health on maternal and child health service utilization and continuum of care in Northern Ghana	Scientific Reports	Ghana	2023	
04	Alhaidari et al [24]	Feasibility and acceptability of text messaging to support antenatal	Journal of Perinatal Medicine	Iraq	2018	Scopus

		healthcare in Iraqi pregnant women: A pilot study.				
05	Ronen et al [10]	Evaluation of a two-way SMS messaging strategy to reduce neonatal mortality: rationale, design and methods of the Mobile WACh NEO randomised controlled trial in Kenya.	BMJ open	Kenya	2021	AISeL
06	Batool et al [25]	Maternal complications: Nuances in mobile interventions for maternal health in urban Pakistan	Proceedings of the Ninth International Conference on Information and Communication Technologies and Development	Pakistan	2017	Google Scholar
07	Atnafu et al [26]	The role of mHealth intervention on maternal and child health service delivery: findings from a randomized controlled field trial in rural Ethiopia	mHealth	Ethiopia	2017	
08	Omole et al [27]	The effect of mobile phone short message service on maternal health in south-west Nigeria	The International Journal of Health Planning and Management	Nigeria	2018	
09	Thompson et al [28]	Connecting mothers to care: Effectiveness and scale-up of an mHealth program in Timor-Leste.	Journal of Global Health	Timor-Leste	2019	
10	Muhoza et al [29]	A mobile-based technology to improve male involvement in antenatal care.	Kabale University Interdisciplinary Research Journal	Uganda	2022	
11	Oliveira-Ciabati et al [30]	SISPRENACEL - MHealth tool to empower PRENACEL strategy.	Procedia Computer Science	Brazil	2017	

12	Kawakatsu et al [31]	Cost-effectiveness of SMS appointment reminders in increasing vaccination uptake in Lagos, Nigeria: A multi-centered randomised controlled trial	Vaccine	Nigeria	2020	Science Direct

3 Results

3.1 SMS App Inventory (RQ1)

3.1.1 Overview of apps

The dataset consists of 12 applications. These ranged from basic, one-way SMS-sending apps to more complex, bidirectional communication platforms that connect pregnant women with healthcare providers throughout and sometimes beyond the pregnancy period. Table 2 provides an overview of the identified apps and offers details on each app's target population, key features, and study design employed to evaluate its effectiveness. App names are given where the authors gave specific names to their developed apps.

Table 2 Overview of apps

App name	Country (region)	Target population	Key features	Study design
The Wired Mothers	Tanzania (Zanzibar)	Pregnant women attending antenatal care at 24 primary health care facilities across six districts on the island of Unguja	• Unidirectional text messaging • a mobile phone voucher system for two-way communication between pregnant women and their primary health care providers.	Pragmatic, cluster-RCT
N/A	Tanzania (Dodoma)	pregnant women	• Provide simple health education (obstetric danger signs, newborn danger signs, Individual birth preparedness, complication readiness) • Engage expecting parents (mother and father) with essential health information. • two-way communication	A quasi-experimental study with a control group is characterised explicitly as a "pre- and post-test with a control group."
T4MCH	Ghana	Pregnant women	• Automated messaging (SMS/voice messages)	Standard guidelines for reporting quasi-experimental studies using the Transparent Reporting of

				Evaluations with Non-randomized Design/Quasi-Experimental Study Design (TREND)
N/A	Iraq	Pregnant women attending an antenatal clinic linked to Al Elwiya Maternity Teaching Hospital	• Automated SMS	Controlled experimental study
Mobile WACh NEO system	Kenya	Pregnant women were recruited from four different facilities in Kenya.	• Two-Way Communication • Automated Messaging • Support for Multiple Languages • Response Management • Participant Tracking • Cost-Free for Participants	RCT
N/A	Pakistan	Pregnant women enrolled in the trial conducted at Lady Willingdon Hospital in Lahore	• Multi-modal communication (SMS and automated voices) • Automated Delivery • Data tracking	RCT
Customised FrontLine SMS	Ethiopia	Women aged 15-49 years who had at least one child	• Automated messaging • Data exchange between CHW and CHW • Contraceptive stock management	Community-based RCT
Maternal Health Plus	Nigeria	Pregnant women attending ANC within the Ife-Ijesa zone.	• Automatic delivery of SMS • Two-Way Communication • Database Management • Language Preference	RCT
Liga Inan	Timor-Leste	Women aged 15-49 years with a child up to 24 months of age.	• Web-based platform connected to a GSM. • Automatic delivery of SMS • voice communication	Quasi-experimental design.
N/A	Uganda	Pregnant women and their partners	• Cloud-Based platform • Monitoring ANC-seeking behaviour. • Automatic delivery of SMS	Pragmatic randomized trial
SISPRENACEL	Brazil	Pregnant women	• Automatic delivery of SMS • Two-Way communication • Individualised interaction management (Chat-like format)	A socio-technical approach using the prototype method.

			• Researcher access • Private cloud deployment	
N/A	Nigeria	Pregnant women	• Automatic delivery of SMS • Customisation (depending on the type of health service) • cloud server • Unique QR code for each user	Multi-centered RCT

N/A= Not Available

Table 3 Detailed app descriptions

Study ID	Content of messages	Frequency	Tools/resources employed for implementation	Duration of the intervention
01	Health education on danger signs in pregnancy, the importance of skilled delivery attendance, and reminders for upcoming antenatal care visits.	The frequency of the messages varied throughout the pregnancy, with an increase in frequency to weekly messages during the last four weeks before delivery.	Specific software name or platforms used for development is not mentioned	The study followed the women until 42 days post-delivery to assess the impact of the mobile phone intervention on perinatal outcomes
02	Obstetric and newborn danger signs & Birth preparedness & Complication readiness	First Trimester: One message per week. Second Trimester: Two messages per week. Third Trimester: Three messages per week.	Specific software name or platform used for development is not mentioned	From the initial ANC visit until the point of delivery
03	The messages include the importance of regular antenatal care visits, the benefits of facility-based deliveries, and the necessity of postnatal care.	weekly	Savana Signatures: design and execution of the project; Salasan Inc: technological framework; Mustimuhw Information Solutions: software solutions	August 1, 2017, to September 30, 2017.
04	General health messages, Reminders to visit PHCC, Nutritional advice, Lifestyle education.	Weekly, every Friday between 4 PM and 6 PM	forat-sms.com: Bulk messaging platform	Not specified
05	Critical information on pregnancy, birth planning, infant care, and emergency responses	From delivery to 2 weeks postpartum, mothers get two daily messages to	Detailed in another paper [32]	From enrolment at 28-36 weeks gestation until six weeks postpartum

		bolster care practices and offer continuous support.		
06	Information about prenatal care, reminders for ultrasound tests, encouragement to follow medical advice and attend scheduled appointments.	It is not specified, but it is mentioned that the app could manage diverse messaging needs across distinct stages of pregnancy.	SMS Service Provider: API SMSAll.pk Telephony software: For automated calls, Asterisk was used, coupled with a Primary Rate Interface (PRI) line to manage multiple concurrent calls.	Two months
07	ANC reminders and Child immunisation	Health extension workers (HEWs) received ANC appointment reminders at gestational weeks 14, 24, 30, and 36. Vaccination appointment reminders were sent at 6, 10, and 14 weeks, and nine months. HEWs then sent a reminder one week prior to monthly vaccinations.	Mobile phones equipped with customised FrontLineSMS & Central server and Local network & Short-code System and GSM Modem subscription	September 2012 to October 2013: 13 months
08	Clinic reminders, Specific pregnancy-related health tips, general tips	Delivered periodically, based on the antenatal care appointment schedule of each participant.	Mobile devices, SMS Enabler version 2.5.5, A MySQL database	December 2013 to December 2014
09	Reminders for care-seeking and promoted safe pregnancy and delivery practices.	Messages were sent twice weekly, precisely every Monday and Thursday.	Mobile devices, web-based applications connected to a GSM gateway	Two years
10	Appointment reminders	Weekly	a cloud-based platform, AfricasTalking API	Nine months
11	information on antenatal care, pregnancy, and delivery topics	Not specified but likely according to pregnancy stages	client-server architecture, CakePHP, and MySQL for data storage, AdminLTE version 1.0 for GUI	April 2015 to May 2016
12	visit reminder messages.	SMS text reminder two days before their scheduled appointments. If clients did not attend their	mobile application linked to a cloud server, with a unique QR code for each user	1st April to 30th June 2019

		appointments, an additional reminder was sent seven days after the original appointment date as a defaulter tracing measure.		

GUI: Graphical User Interface; QR code: quick-response code; RCT: randomised controlled trial

3.1.2 Detailed app descriptions

This subsection comprehensively describes each application based on extracted data. Essential intervention details, such as message content, sending frequencies, and the development tools used (see Table 3), are provided.

3.2 Effectiveness Evidence (RQ2)

3.2.1 Overview of studies

Among the 12 studies, six primary outcomes were identified and further classified into effectiveness and safety domains, as well as primary and secondary categories. **Primary** effectiveness outcomes included improved attendance (N=9) and skilled delivery attendance (N=4). The primary safety outcomes included a reduction in neonatal mortality (N=1) and reduced complications (N=1). Secondary effectiveness outcomes included increased knowledge (N=3) and patient satisfaction (N=1). eTable 5 provides a detailed breakdown of these outcomes categorised by study design.

Regarding the message content sent to participants (including women and, in one case, their male partners [29]), the key themes revolved around appointment reminders (observed in 11 studies, representing 91.7% of cases), educational content (75% of cases), emergency or danger alerts (16.7% of cases), and combinations of these themes (66.7% of cases). eFig 6 available in the supplementary elements illustrates the frequency of SMS content types across the different apps. For the detailed content types per study, please refer to Table 3.

The SMS-sending frequency was consistent across the studies. In five studies, messages were sent weekly, while in other cases, the frequency was adjusted according to the pregnancy stage or specific contextual timing. For instance, in the setup described by Masoi and Kibusi [9], the frequency varied by pregnancy stage: one message per week during the first trimester, two per week in the second trimester, and three per week in the third trimester. These variations were noted in eight studies, including some that used weekly SMS during certain phases or daily SMS from delivery to two weeks postpartum [10]. A common trend in apps using varied frequencies was a systematic increase in message intervals as the delivery date approached. Table 2 provides detailed information on each application. The intervention durations varied,

with some lasting less than three months (16.7%), others ranging from 3 to 6 months (16.7%), some spanning 6 to 12 months (41.7%), and three studies exceeding 12 months (25%).

The breakdown of development tools or approaches for app implementation is as follows. An SMS gateway (26.67% usage rate among evaluated apps) facilitates the efficient delivery and receipt of text messages, making it suitable for large-scale messaging campaigns due to its simplicity [33]. Custom apps (36.67%) provide personalised features like interactive messaging and data analytics, demanding substantial development resources while offering significant customisation. Third-party platforms (16.67%) are pre-built solutions with scheduling and often analytics features but may lack the flexibility of custom apps. A combined approach (20% usage rate) combines the strengths of multiple tools, such as using a custom app for analytics along with an SMS gateway or a third-party platform for messaging, allowing for simplicity, customisation, and scalability tailored to various SMS interventions [34]. The specific names and/or platforms used by each app (when provided in the article corpus) are listed in Table 2.

3.2.2 Study findings

Unsurprisingly, all studies highlighted the significant impact of SMS-based interventions on maternal healthcare. Lund et al. [12] discovered a substantial rise in ANC attendance, with women adhering to the World Health Organization (WHO) recommendations for four or more visits. The same has been observed in other studies [8,24,26,29]. Moreover, they [12] observed an increase in skilled delivery attendance among urban women, with an odds ratio (OR) of 5.73 (95% CI: 1.51-21.81). Notably, it significantly reduced perinatal mortality, with an OR of 0.50 (95% CI: 0.27-0.93). Ronen et al. [10], in the pilot phase [35] of their ongoing randomised controlled study (Mobile WACh NEO RCT), identified that among women residing in areas with elevated rates of stillbirth, perinatal and infant mortality, increasing maternal age was the sole predictor of stillbirth. It is essential to highlight that, although we included their main study in our dataset, the results have not yet been compiled and published as of the writing of this paper. The trial concluded with participant enrolment (5,020 participants) on 30 June 2022 and follow-up was scheduled to continue until February 2023 [36]. Consequently, we relied on the pilot-phase results [35]. Table 4 shows the different studies along with the effect sizes and statistical significance of their primary outcomes, as reported in the content of the papers.

3.2.3 Subgroup analysis

Subgroup analysis explored the distribution and outcomes of the interventions across regions, study designs, and intervention types, providing a better understanding of the factors influencing their effectiveness.

3.2.3.1 Regional distribution and significance

Regional distribution analysis revealed notable differences in the number of studies, outcomes, and study-level significance across global regions. Five studies were conducted in East Africa (Ethiopia, Kenya, Tanzania, and Uganda). Of these studies, four reported outcomes that were statistically significant [9,12,26,29], and one did not indicate significance (pilot)[35]. This highlights the region's robust research activity. Three studies in West Africa (Ghana and Nigeria) emphasised the effectiveness of interventions in this region [8,27]. Asia (Pakistan and

Timor-Leste), the Middle East (Iraq), and South America (Brazil) are underrepresented with only one study per country.

3.2.3.2 *Impact of study designs*

Randomised controlled trials (RCTs) dominated the dataset, with eight studies spanning East and West Africa and Asia. Of these, five demonstrated all outcomes as significant, while two reported partial significance (see eTable 6). This reflects the robustness of the RCT design in yielding significant findings, albeit with some variations. Quasi-experimental studies, the second most common design, include 3 studies from Ghana, Tanzania, and Timor-Leste. Two of these achieved full significance, while one fell under the 'not applicable' category. A sociotechnical approach using a prototype method is less common, as represented by a single study. It reports fully significant outcomes, indicating potential but limited generalisability due to their low frequency.

Table 4 Effectiveness evidence

Study	Main outcomes & significance	Conclusion
[12]	Significant effect on antenatal care attendance, with an odds ratio (OR) of 2.39 and a 95% confidence interval (CI) of 1.03 to 5.55. Increased skilled delivery attendance among urban women, with an OR of 5.73 and a 95% CI of 1.51 to 21.81. Significant reduction in perinatal mortality with the mobile phone intervention, with an OR of 0.50 and a 95% CI of 0.27 to 0.93.	The study illustrates that the mobile phone intervention effectively improved critical maternal health outcomes and significantly reduced perinatal mortality.
[9]	Significant increase in knowledge about obstetric and newborn danger signs (large effect size 85%). Higher scores in birth preparedness and complication readiness (effect size of 90%).	The significant effect sizes in both primary outcomes suggest that the intervention had a robust impact on the participants.
[8]	Increase ANC attendance, with an average treatment effect (ATE) of about eighteen percentage points. Increase in the number of women opting for facility-based delivery (14%). PNC attendance also increased with the intervention (27%).	The results underscore the intervention's positive effect on maternal health, notably increasing attendance and utilisation of essential maternal and child health services.
[24]	Over 85% of the participants in the intervention group expressed satisfaction with the SMS-based support. Statistically significant increase in the median number of ANC visits compared.	The intervention significantly increased engagement in ANC, and positive feedback was received from participants regarding satisfaction.
[35]	The stillbirth rate observed was sixteen per 1,000 pregnancies. There were seventeen neonatal deaths during the study period, leading to a neonatal mortality rate of 22 per 1,000 live births. The perinatal death rate (including stillbirths and neonatal deaths up to 6 days of age) was 36 per 1,000 pregnancies.	This pilot phase identified that among women residing in areas with elevated rates of stillbirth, perinatal, and infant mortality, increasing maternal age was the sole predictor of stillbirth.

[25]	Significant improvements in knowledge about pregnancy and childbirth. No significant difference in the number of follow-up visits among the groups.	The study revealed substantial knowledge gains about pregnancy among participants, but the effect of increasing follow-up visits remained ambiguous due to social norms and logistical challenges.
[26]	Significant increase in the proportion of mothers attending more than four ANC visits in the intervention. Ezha (Treatment 1): increased from 45.32% to 59.84%; Abeshge (Treatment 2): increased from 15.8% to 31.5% ; Sodo (Control): decreased from 24.48% to 23.27% ; P-value: P<0.001 for Ezha and Abeshge. There was a significant increase in deliveries attended by skilled health workers in the intervention areas Ezha (Treatment 1): Increased from 26.79% to 55.23%; Abeshge (Treatment 2): Increased from 41.96% to 63.54% ; Sodo (Control): Increased from 21.79% to 52.05%. P<0.001 in Ezha, indicating robust improvement	These findings highlight the improvements in healthcare services delivered to mothers and children due to the mobile intervention, with the most significant impact seen in antenatal care attendance and skilled deliveries. However, limitations in the intervention's effectiveness were noted in contraceptive utilisation and immunisation coverage.
[27]	There was a significant increase in the proportion of facility-based deliveries among the intervention (29%) and control groups (13%). 96.6% of participants in the intervention group expressed support for the SMS intervention as a platform for maternal health promotion.	The intervention significantly improved maternal health behaviour by increasing the rate of facility-based deliveries among pregnant women.
[28]	No significant increase in the number of women receiving four or more antenatal care visits. (OR = 1.0 (95% CI: 0.54-0.9)). Significant increase in the likelihood of women having a skilled birth attendant present during delivery (OR = 1.9 (95% CI: 1.1-3.2)). Significant increase in the likelihood of women delivering in a health facility (OR= 1.9 (95% CI: 1.1-3.6)).	The Liga Inan program significantly improved skilled birth attendance, facility deliveries, postpartum care, and newborn health checks, though it did not notably affect antenatal care visits.
[29]	Increase in male involvement in ANC with a 50% adherence rate among male partners, meaning 10 out of the 20 male partners attended four consecutive antenatal visits. Improved ANC-seeking behaviour among pregnant mothers.	The results suggest that SMS-based interventions can positively impact male participation in ANC and improve pregnant mothers' attendance rates.
[30]	The system received a high overall score of 6.33 out of 7 in usability, with the highest scores in system usefulness (6.61) and the lowest in information quality (6.03). High engagement with 22,296 scheduled SMS delivered, received 1,249 messages from participants, and 1,823 SMS inquiries answered.	These results underscore the app's effectiveness in achieving high user satisfaction and engagement and the potential

	The system could be adapted for national-level deployment	for broader application in maternal health interventions.
[31]	Significant increase in the return rate for child vaccinations in the intervention group (4.8% to 6.0% higher return rate). No significant differences were observed in the return rates for ANC and family planning services between the intervention and control groups (Adjusted odds ratios close to 1)	The results indicate that SMS reminders can enhance adherence to vaccination schedules, though their effectiveness may differ across health services, likely influenced by recipients' perceived urgency or importance of the service [31].

3.2.3.3 Effectiveness of intervention types

The intervention-type analysis revealed critical trends in the study's effectiveness and applicability. Mixed interventions (educational and reminders) are the most prevalent, with six studies across diverse regions including Africa, Asia, and the Middle East. Among these, five reported full significance, while one indicated partial significance. Educational messages, implemented in Brazil, Kenya, and Tanzania, are associated with three studies, of which two demonstrated significant outcomes and one was categorised as "not applicable." Reminders applied in Ethiopia, Nigeria, and Uganda show similar proportions, with two studies achieving full significance and one partial significance (refer to eFig. 7).

4 Discussion

The findings underscore the potential of SMS-based interventions to enhance ANC attendance, maternal health knowledge, and service utilisation in LMICs. Across the studies reviewed, SMS interventions demonstrated varying degrees of effectiveness (see Table 4), reflecting diversity in implementation approaches, population contexts, and healthcare systems.

Studies [12,26] highlighted substantial improvements in ANC attendance and skilled delivery rates, with odds ratios and effect sizes indicating robust effects. These findings suggest that SMS reminders and educational messages can effectively address common barriers to maternal healthcare, such as a lack of awareness or forgetfulness. However, the mixed outcomes observed in some studies, such as [28], who reported a limited impact on ANC visits despite significant improvements in skilled delivery and facility-based births, indicate the need for context-specific tailoring of message content and delivery frequency.

The review highlights the strong influence of SMS-based interventions on maternal health knowledge and birth preparedness. For instance, Masoi and Kibusi [9] reported large effect sizes in knowledge about obstetric and newborn danger signs, while Batool et al. [25] emphasised knowledge gains despite the limited impact on follow-up visits. Effective interventions appear to combine timely reminders with actionable health education, reinforcing preparedness, and engagement. Participant satisfaction was consistently high across studies

such as Alhaidari et al. [24] and Oliveira-Ciabati et al. [30], where users expressed positive feedback about the usability and relevance of SMS interventions. High engagement levels, including two-way communication and interactive features, were associated with better adherence to health recommendations. These results suggest that user-centred design and feedback mechanisms are critical to the success and sustainability of SMS interventions. However, interactive features in some cases might not be ideal in low resource settings as it implies the use of advanced technologies (smartphones) that are not necessarily accessible to the targeted women.

Our subgroup analysis revealed regional, methodological, and intervention-type variations in the effectiveness of the SMS-based ANC interventions. East Africa had the highest research activity, with most studies reporting statistically significant outcomes, whereas other regions, including West Africa, Asia, the Middle East, and South America, were underrepresented. RCTs demonstrated the strongest evidence. Mixed interventions combining educational messages and reminders were the most effective, highlighting the importance of multifaceted approaches over stand-alone reminders or educational messages. These findings emphasise the need for further research in underrepresented regions and deeper exploration of intervention strategies to optimise SMS-based maternal health programs.

Despite these positive findings, this review also revealed limitations in the effectiveness of SMS interventions. For instance, Kawakatsu et al. [31] reported variability in effectiveness across different health services, such as higher adherence to vaccination schedules but no significant improvement in ANC or family planning return rates. Others [25] have identified logistical barriers and social norms as factors that limit follow-up visits. These mixed outcomes emphasise the need for comprehensive program designs that account for broader systemic and sociocultural factors influencing maternal health behaviours.

Moreover, based on our risk assessment, most studies were categorised as having “some concerns”, with no studies excluded because of critical methodological flaws. While this suggests a moderate level of reliability, certain biases may still affect the interpretation of the results. For example, [12] exhibited high bias in two domains (D2: Bias due to deviations from intended intervention and D4: Bias in the measurement of outcomes), which may impact the validity of its reported reduction in perinatal mortality and maternal health improvements. Similarly, Muhoza et al. [29] had a high D2, suggesting potential concerns regarding deviations from the intended intervention (see eFigure 1). In the case of [8,9], serious bias due to confounding factors (D1, ROBINS-I) may influence the observed significant effect sizes in primary outcomes and maternal health benefits. Additionally, Thompson et al. [28], who demonstrated improvements in skilled birth attendance and facility deliveries, had a serious concern with D5 (bias due to missing data), potentially affecting the reliability of their findings (see eFigure 2). The study [30], assessed with a checklist for reporting the development and evaluation of complex interventions in healthcare, was concerned with sustainability (D8), which may limit its long-term applicability (see eFigure 5).

Despite these biases, the collective evidence supports the positive impact of SMS-based interventions on ANC attendance, maternal health outcomes, and service utilisation. However, these findings should be interpreted with caution because of potential methodological limitations.

Limitations and future research

Our study acknowledges several limitations that may influence the generalisability and applicability of the findings. This systematic review was not pre-registered in a database, which may be considered a limitation. However, as no clinical data were involved, registration was not mandatory. We ensured methodological transparency by outlining our search strategy, inclusion criteria, and quality assessment approach. The review process was conducted by a single reviewer, which, despite ensuring a consistent approach, could introduce bias and limit the breadth of interpretation typically enriched by multi-reviewer analyses. Resource constraints and the availability of language-proficient subject matter experts necessitate this approach. To mitigate potential bias, rigorous adherence to predefined inclusion and exclusion criteria was maintained throughout the process. Although not optimal, this approach ensured the feasibility of the study within the available resources. Moreover, given that this study is focused solely on a systematic review, as stated, we did not conduct quantitative statistical analyses typically required for meta-analysis, such as pooled effect size calculations or heterogeneity tests (e.g. prediction Intervals, or I^2)[37]. While these methods could have added quantitative depth, they were not necessary to achieve the primary objective of synthesising and qualitatively analysing the evidence to inform our research focus. This methodological void should be addressed in future studies. Although we identified a concentration of studies from East Africa (5 of 12), this likely reflects the higher volume of SMS-based ANC interventions conducted and published in this region. Despite our comprehensive search strategy, studies from other LMICs may have been underrepresented or uncaptured, highlighting the need for further research in diverse geographical contexts to improve generalisability.

5 Conclusion

This review shows that mobile health interventions hold significant promise for improving maternal health outcomes, particularly in low-and middle-income countries (see eFig. 8). The interventions demonstrated positive effects on ANC attendance, health knowledge, and general maternal health behaviours, underscoring the value of digital health tools in resource-limited settings. However, the effectiveness of these interventions varied widely and was influenced by factors such as the content and frequency of messages, and the implementation tools used. Continued efforts in this field can significantly reduce barriers to antenatal care and improve maternal and child health outcomes.

6 Declaration of competing interest

The authors have no conflicts of interest to declare relevant to this paper's content.

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9 Declaration of generative AI and AI-assisted technologies in the writing process

While preparing this work, the authors used GPT 4 and 4o to improve readability and language. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

10 Data availability statement

All data relevant to the study are included in the article or are uploaded as supplementary information. Extracted data, both raw and coded, are available upon reasonable request from the corresponding author.

11 Ethics statements

11.1 Patient consent for publication

Not applicable.

11.2 Ethics approval

This study did not involve human participants. Ethical approval was not required for this systematic review because all the data were obtained from published articles.

12 Authors' contribution

MK: Project administration, conceptualisation, methodology, writing original draft preparation, data curation, formal analysis after paper selection. MM: Conceptualisation, writing-reviewing, editing and supervision. All the authors approved the final manuscript. The corresponding author (MK), as guarantor, accepts full responsibility for the finished article, has access to all data, and controlled the decision to publish.

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14 Figure legends

Figure 1: Flow Diagram of the search

eFigure 1: Traffic-light plot ROB2

eFigure 2: Trafic-light plot ROBINS-I

eFigure 3: Summary plot ROB2

eFigure 4: Summary Plot ROBINS-I

eFigure 5: Traffic-light plot Checklist for reporting development

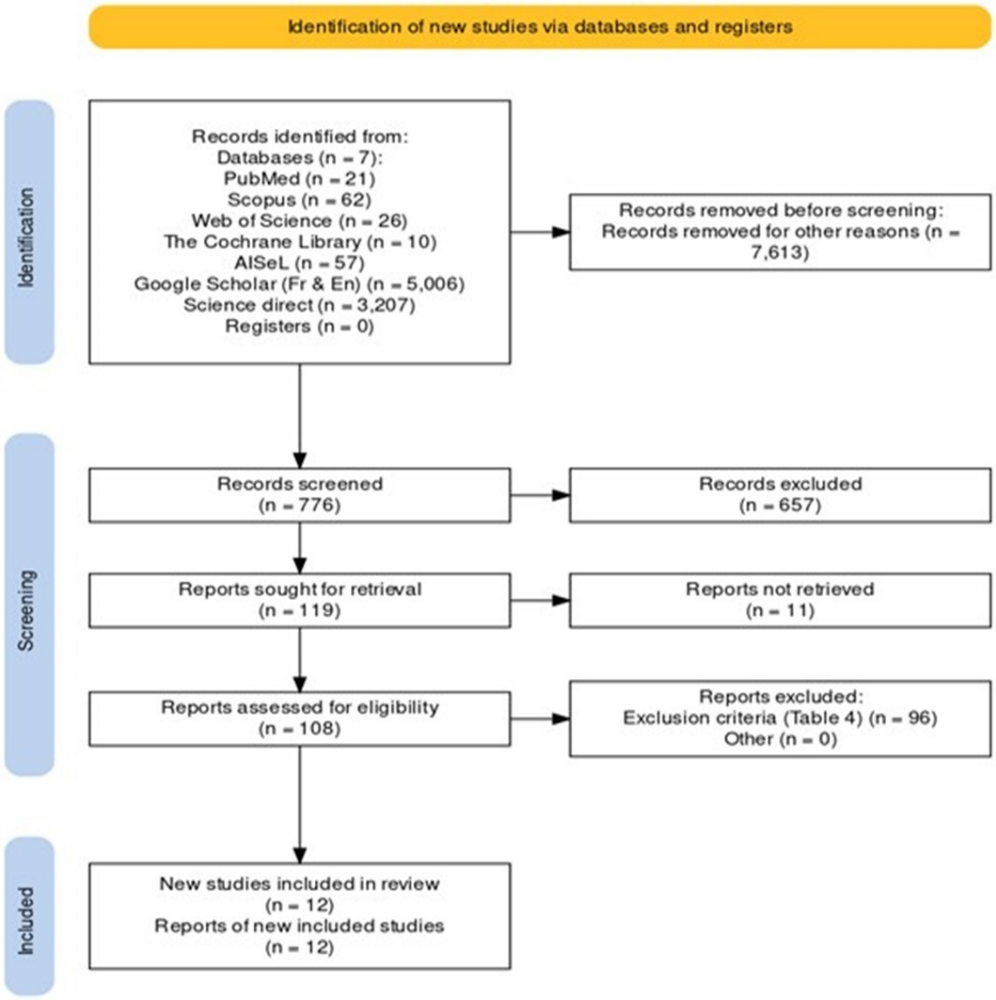
eFigure 6: Content of SMS

eFigure 7: Effectiveness of intervention types

eFigure 8: SMS-Based apps on the map

15 Appendix

PRISMA checklist



Flow Diagram of the search

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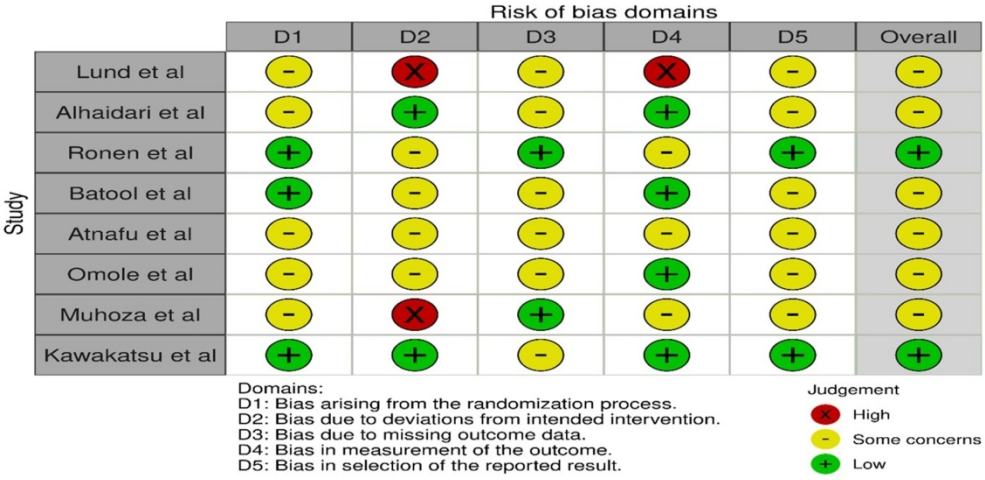

Traffic-light plot ROB2

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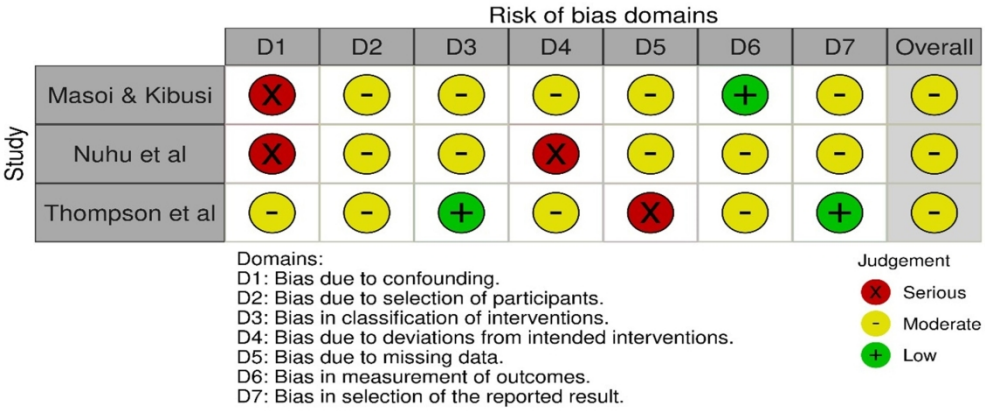

Trafic-light plot ROBINS-I

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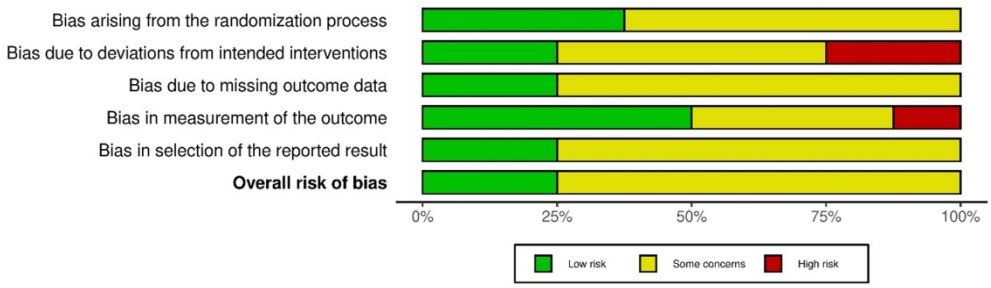

Summary plot ROB2

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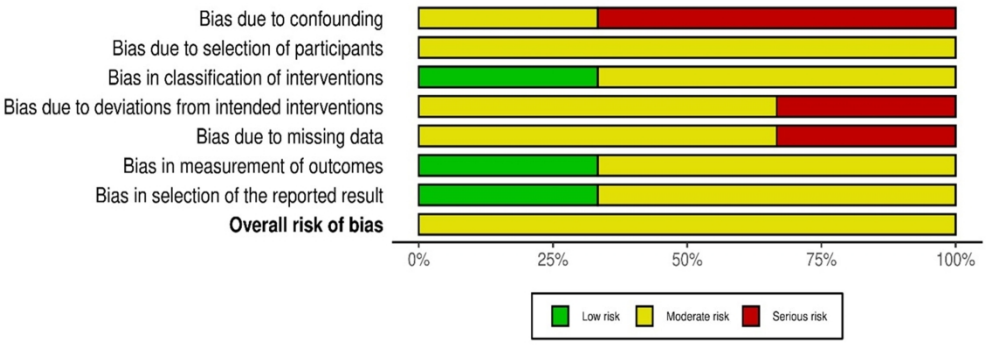

Summary Plot ROBINS-I

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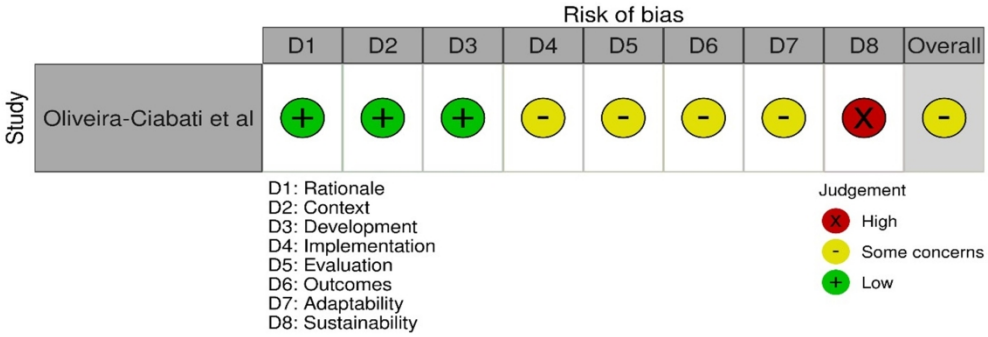

Traffic-light plot Checklist for reporting development

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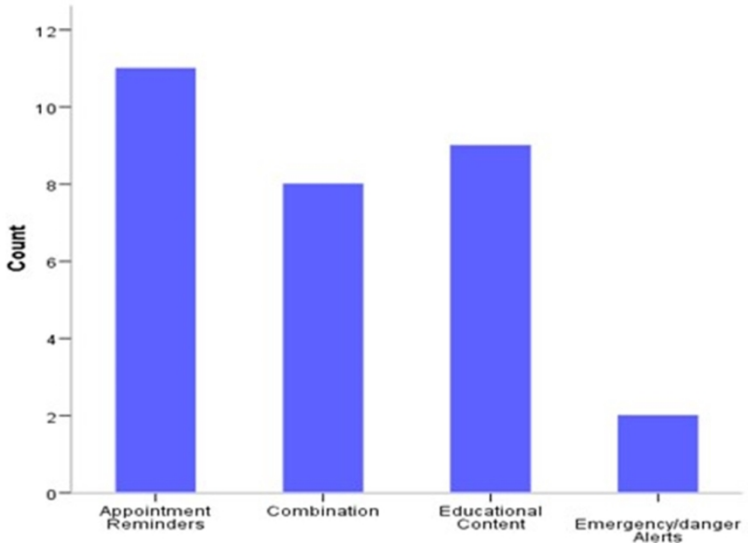

Content of SMS

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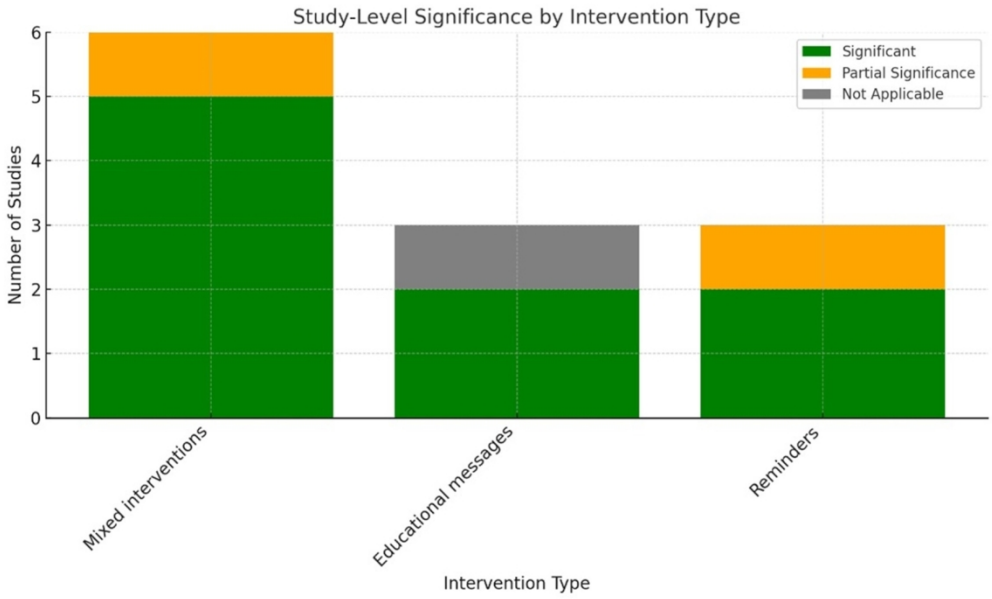

Effectiveness of intervention types

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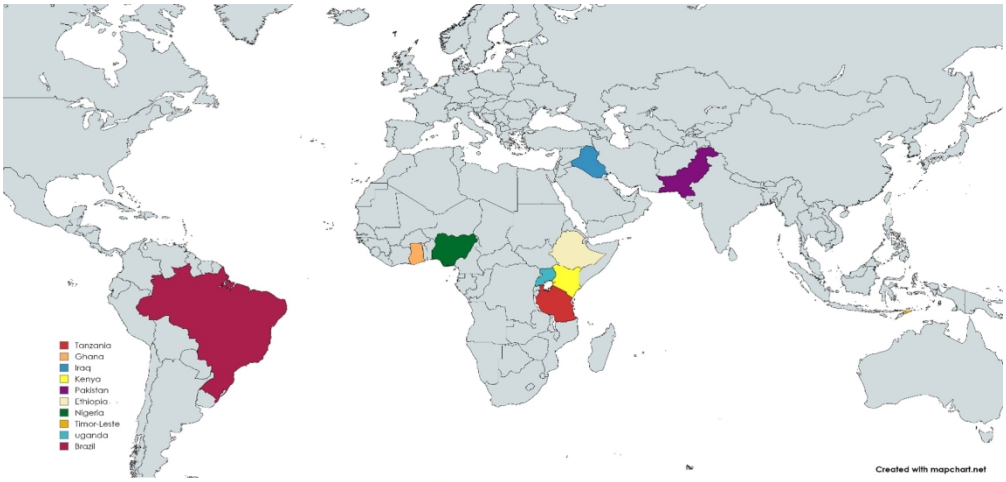

eFigure 8 SMS-Based apps on the map

SMS-Based apps on the map

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Supplementary tables and figures

eTable 1 Full search strategy

	PubMed	Scopus	Web of Science	The Cochrane Library	**AISeL**	**Google Scholar**	**Science Direct**
Search done in	Title and Abstract	Title, Abstract and Keywords	Abstract	Title, Abstract and Keywords	All fields	All fields	All fields
Language	English					English and french	English
Year filter	2014-2024						
English search strings	("SMS-based applications" OR "text messaging" OR "mobile health" OR "mHealth") AND ("antenatal care" OR "prenatal care" OR "pregnancy care" OR "ANC") AND ("developing countries" OR "low-income countries" OR "resource-limited settings")						
French search string	("applications basées sur SMS" OU "messagerie texte" OU "santé mobile" OU "mSanté") ET ("soins prénatals" OU "soins anténataux" OU "soins pendant la grossesse" OU "CPN") ET ("pays en développement" OU "pays à faible revenu" OU "contextes à ressources limitées")						

eTable 2. Summary of search results

	PubMed	Scopus	Web of Science	The Cochrane Library	**AISeL**	**Google Scholar**		**Science Direct**	**Total**
						En	Fr		
Results (considered)	21	62	26	10	57	4750 (200)	256(200)	3207(200)	776
Suitable studies	3	1	0	0	1	5	0	2	12

eTable 3 Inclusion and exclusion criteria

Description	**Inclusion**	**Inclusion justification**	**Exclusion**	**Exclusion justification**
Study Design	Randomised controlled trials (RCTs), quasi-experimental, observational, and qualitative studies	Allows for a comprehensive understanding of different aspects of SMS-based interventions	Editorials, opinion pieces, reviews, and studies without primary data or clear outcomes related to antenatal	They do not provide empirical data necessary for a systematic review

	that provide data on the implementation, usage, and outcomes of SMS-based antenatal care interventions.	from efficacy to real-world application and user experiences	care and SMS-based interventions.	
Population	Studies involving pregnant women in developing countries. This can include women of all ages, ethnicities, and stages of pregnancy.	To ensure that the findings are relevant to populations where SMS-based interventions might be most necessary and effective due to limited healthcare access.	Studies focusing on populations outside of developing countries or on non-pregnant women.	To maintain the review's focus on the specific needs and context of pregnant women in resource-limited settings.
Intervention	Studies that focus on SMS-based applications designed to improve antenatal care information and attendance. That includes interventions promoting health education, appointment reminders, health monitoring, and support through text messaging.	To evaluate the effectiveness of this technology in enhancing ANC.	Studies that do not specifically use SMS-based communication as a primary method for delivering antenatal care information or support.	To ensure that the results are specific to the impact of SMS-based interventions without the confounding effects of other communication technologies.
Comparators	Studies with or without a control group. For those with a control group, the comparison can be standard care, no intervention, or other digital health interventions not using SMS.	To allow for a broader range of data on the effectiveness of SMS interventions, including comparative analyses against different forms of care.	Studies where the control group is subjected to interventions primarily based on SMS technology; studies that do not clearly describe the comparator.	To clearly distinguish the effect of SMS interventions from other variables.

Outcomes	Studies that measure outcomes related to antenatal care include improvements in antenatal care attendance, enhanced knowledge of antenatal health, improved pregnancy outcomes, and user satisfaction with the SMS service.	ensures that the review directly addresses the impact of SMS interventions on key health metrics and patient satisfaction.	Studies that do not report specific outcomes related to antenatal care	To maintain clarity and relevance.
Publication date	Studies published within the last ten years, from the year 2014	To ensure that the data reflects recent advancements in SMS technology and contemporary healthcare contexts.	Studies published more than ten years ago.	To avoid data that may not accurately reflect current technologies or healthcare practices.
Language	Content written in English or French	To expand the scope of the literature reviewed and due to language capabilities.	Content not written in English or French	To ensure quality due to language proficiency constraints.

eTable 4 Data extraction form

Item	Value
Study Identification	
Study ID	Identification
Author name	Name(s) of the author(s)
Title	Title of the paper
Journal	Journal where the paper is published
Year	Year of publication
Study design	randomised controlled trial, observational study, etc
Country	The country where the study was conducted
Study Participants	
Population description	Accurate description of the population
Sample size	value
Inclusion criteria	Main criteria reported

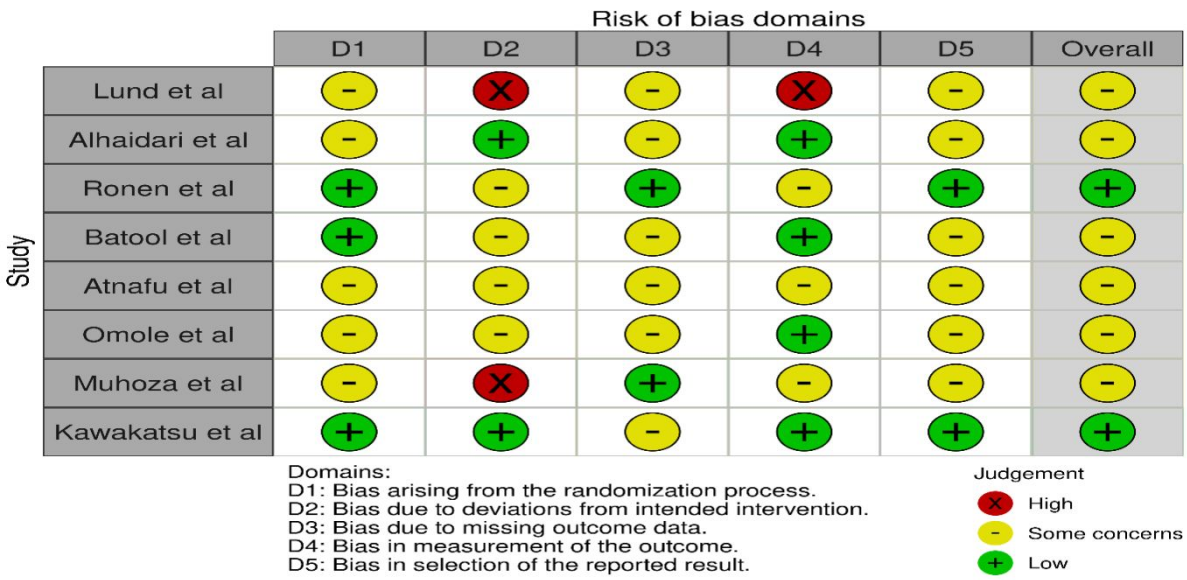
Exclusion criteria	Main criteria reported
Intervention Details	
Description of the SMS-based application	General description with purpose
Content of the SMS-based application	Content of the messages
Message sending frequency of the app	frequency of messages
Tools employed for the implementation of the app	Resources and tools employed for the implementation and/or requirements
Duration of the intervention	Duration as reported
Control or comparator interventions	As reported, if applicable
Outcomes	
Primary outcomes	Improve antenatal care attendance, knowledge enhancement, vaccination visits, satisfaction, etc.
Secondary outcomes	As reported, if applicable
Outcome measurement tools and methods	As reported
Results	
Key findings	Summary of results related to primary and secondary outcomes
Statistical significance	If applicable
Limitations	Limitations reported by the study
Quality Assessment	
Risk of bias assessment	For each study, depending on the study design

*eTable 5 Study design * Outcome*

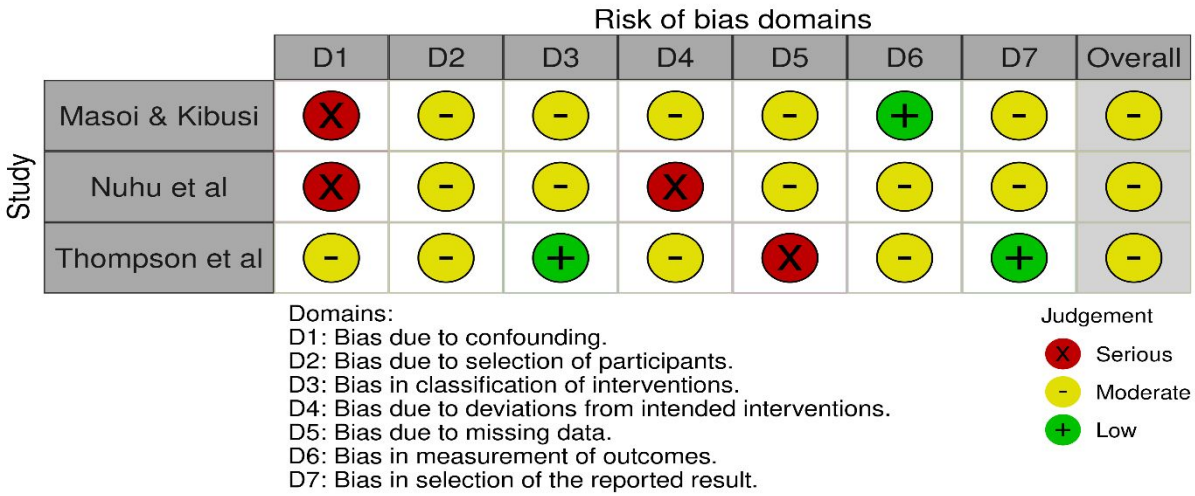
		Outcome						
		Effectiveness				Safety		Others
		Primary		Secondary		Primary		
		Improved Attendance	Skilled delivery attendance	Increased Knowledge	patient satisfaction	Neonatal mortality	Reduced Complications	
Study design	RCT	7	2	1	1	1	0	1
	Non-RCT	2	2	1	0	0	1	1
	Other	0	0	1	0	0	0	1
Total		9	4	3	1	1	1	3

eTable 6. Impact of study design

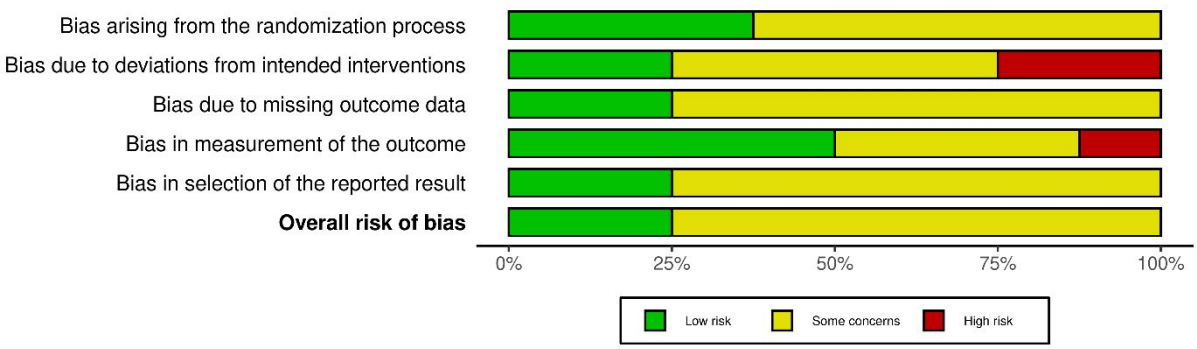
Study Design	Total	Significant_Studies	Partial_Significant_Studies	Not Applicable_Studies	Regions covered
RCT	8	5	2	1	Ethiopia, Kenya, Nigeria, Pakistan, Tanzania, Uganda, Iraq
QE	3	3	0	0	Ghana, Tanzania, Timor-Leste
Sociotechnical approach using the prototype method.	1	1	0	0	Brazil



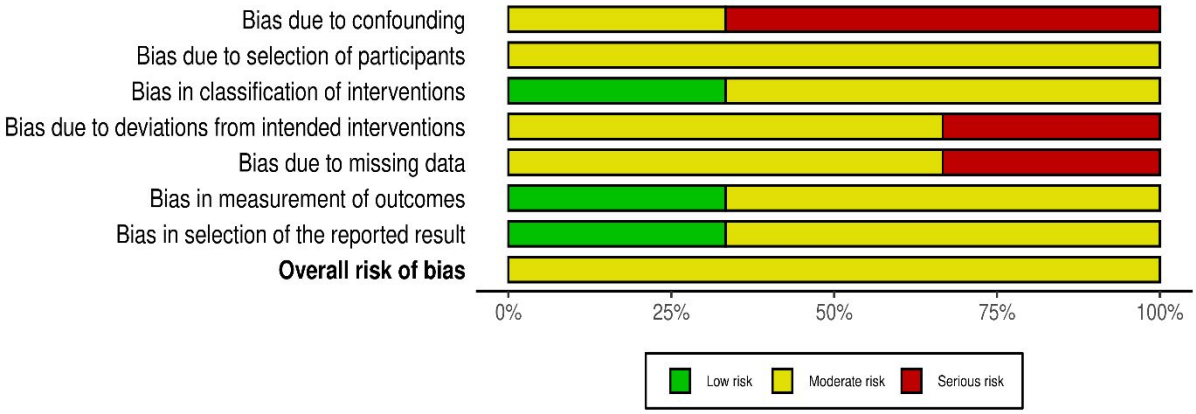
eFigure 1 Traffic-light plot ROB2



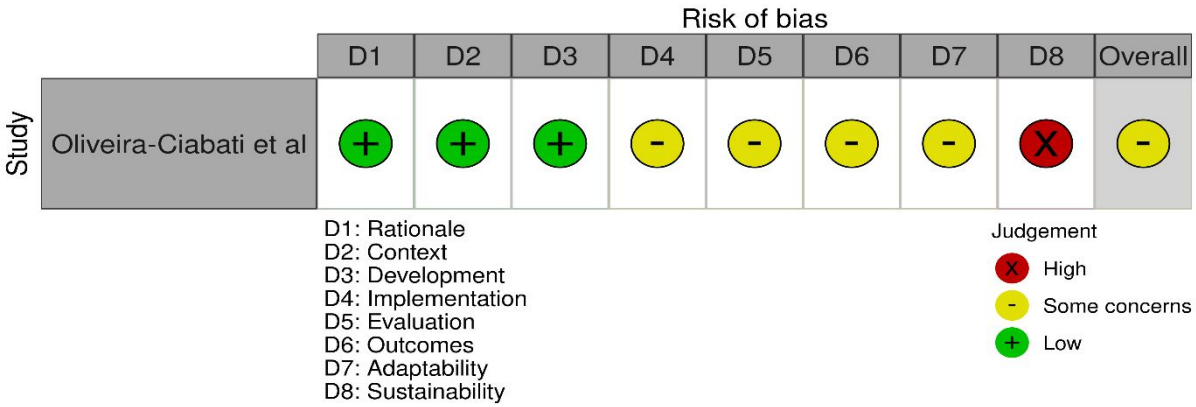
eFigure 2 Trafic-light plot ROBINS-I



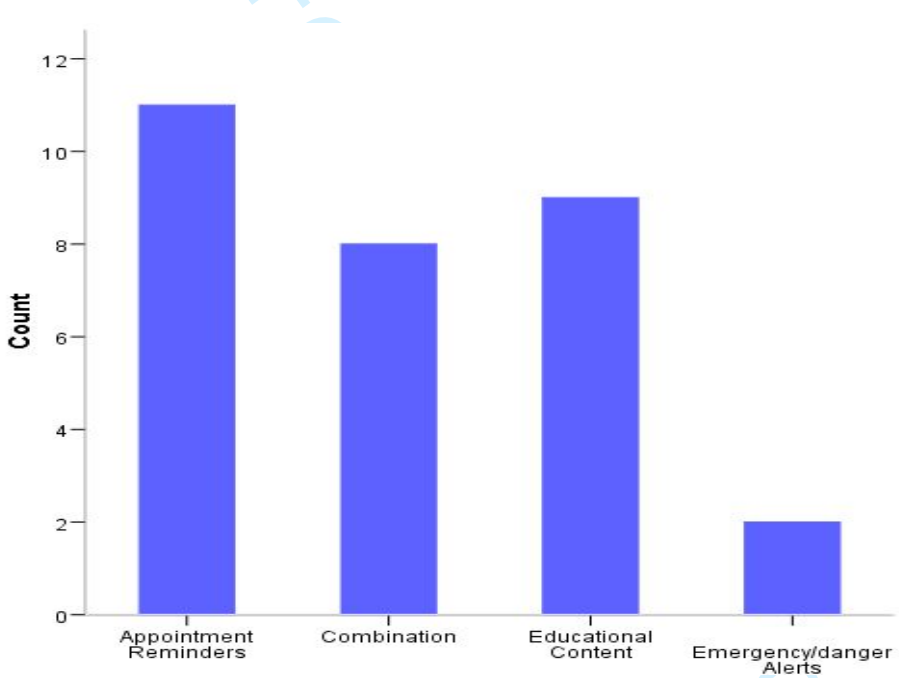
eFigure 3 Summary plot ROB2.



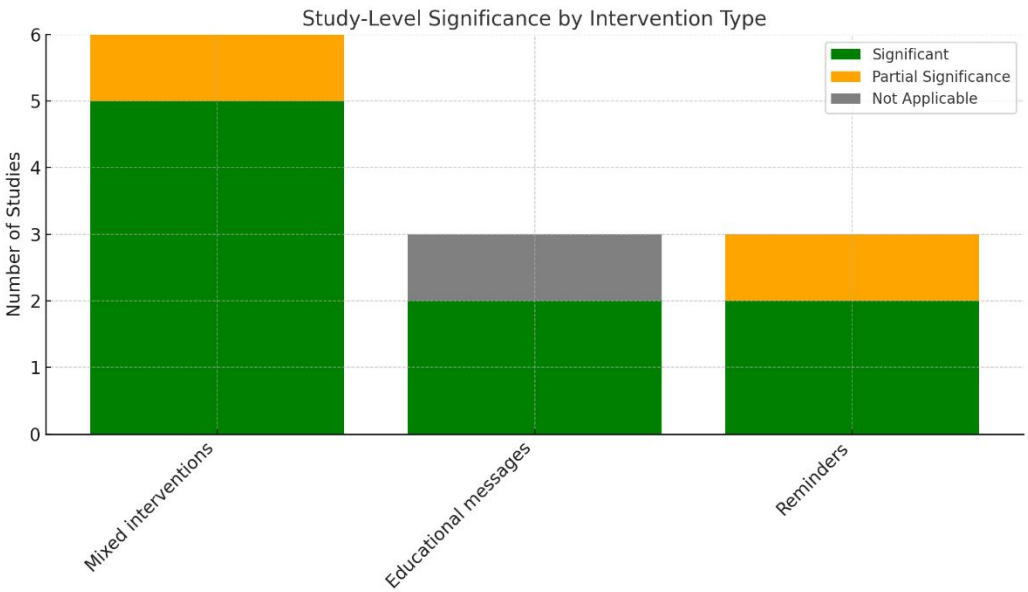
eFigure 4 Summary Plot ROBINS-I



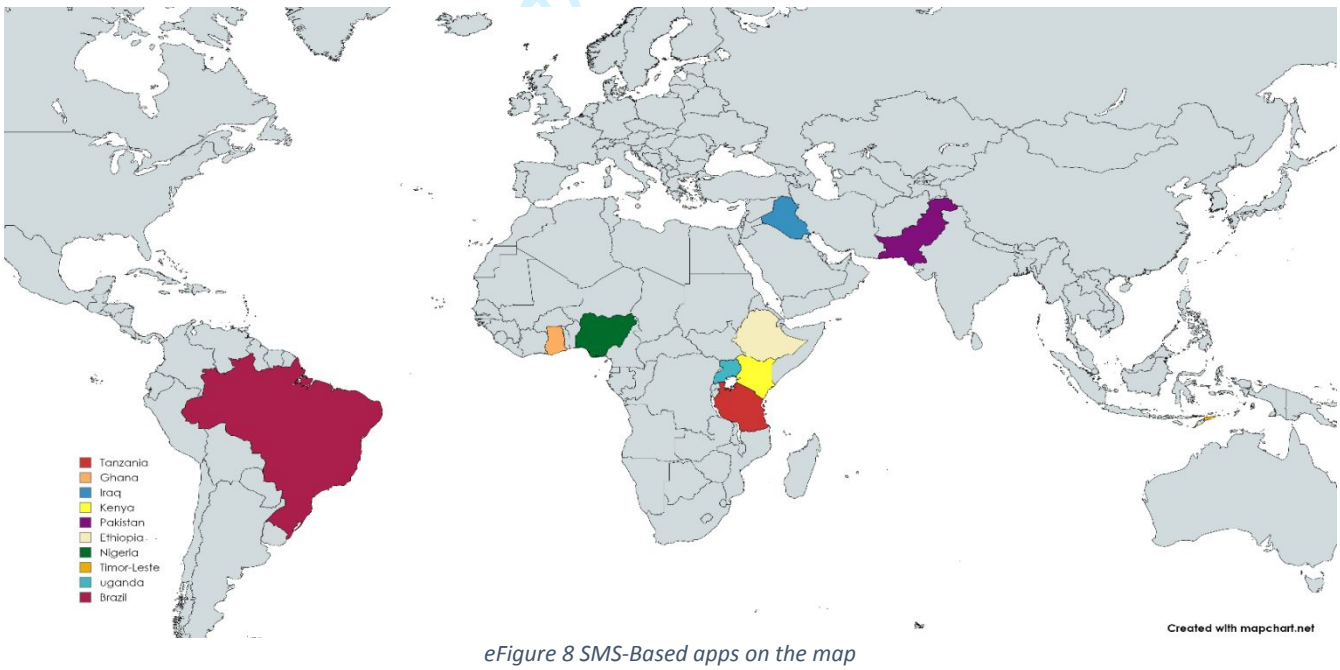
eFigure 5 Traffic-light plot Checklist for reporting development.



eFigure 6 Content of SMS



eFigure 7 Effectiveness of intervention types



eFigure 8 SMS-Based apps on the map

eFigure legends

eFigure1: Traffic-light plot ROB2

eFigure2: Trafic-light plot ROBINS-I

eFigure3: Summary plot ROB2.

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eFigure5: Traffic-light plot Checklist for reporting development.

eFigure6: Content of SMS

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PRISMA 2020 for Abstracts Checklist

Section and Topic	Item #	Checklist item	Reported (Yes/No)
TITLE			
Title	1	Identify the report as a systematic review.	Yes
BACKGROUND			
Objectives	2	Provide an explicit statement of the main objective(s) or question(s) the review addresses.	Yes
METHODS			
Eligibility criteria	3	Specify the inclusion and exclusion criteria for the review.	Yes
Information sources	4	Specify the information sources (e.g. databases, registers) used to identify studies and the date when each was last searched.	Yes
Risk of bias	5	Specify the methods used to assess risk of bias in the included studies.	Yes
Synthesis of results	6	Specify the methods used to present and synthesise results.	Yes
RESULTS			
Included studies	7	Give the total number of included studies and participants and summarise relevant characteristics of studies.	Yes
Synthesis of results	8	Present results for main outcomes, preferably indicating the number of included studies and participants for each. If meta-analysis was done, report the summary estimate and confidence/credible interval. If comparing groups, indicate the direction of the effect (i.e. which group is favoured).	Yes
DISCUSSION			
Limitations of evidence	9	Provide a brief summary of the limitations of the evidence included in the review (e.g. study risk of bias, inconsistency and imprecision).	Yes
Interpretation	10	Provide a general interpretation of the results and important implications.	Yes
OTHER			
Funding	11	Specify the primary source of funding for the review.	Yes
Registration	12	Provide the register name and registration number.	N/A

PRISMA 2020 CHECKLIST

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Title, page 1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Abstract, page 1
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	page 2-3
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Page 4
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Page 4-5
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Page 4
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Page 4
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Page 4-5
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Page 3-5, page 17-18
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Page 5
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Page 5
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Page 6
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	NA
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Page 4-5
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	NA
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	NA
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	NA

Section and Topic	Item #	Checklist item	Location where item is reported
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	Page 14
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	NA
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	NA
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	NA
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Page 4-5
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Page 4-5
Study characteristics	17	Cite each included study and present its characteristics.	Page 6-8
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Page 6
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimates and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Page 14-16
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Page 6,page 19
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	NA
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	NA
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	NA
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	Page 6, page 19
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	NA
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Page 17
	23b	Discuss any limitations of the evidence included in the review.	Page 18
	23c	Discuss any limitations of the review processes used.	Page 18
	23d	Discuss implications of the results for practice, policy, and future research.	Page 17-18
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	NA
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	NA
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	NA
Support	25	Describe sources of financial or non-financial support for the review, and	Page 19

Section and Topic	Item #	Checklist item	Location where item is reported
		the role of the funders or sponsors in the review.	
Competing interests	26	Declare any competing interests of review authors.	Page 19
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Page 19