Bridging the Gap: Evaluating the Effectiveness of Mhealth Interventions in Improving Antenatal Care Uptake and Reducing Maternal Mortality in Rural Northern Nigeria

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Abstract: This systematic review and meta-analysis evaluate the effectiveness of mobile health (mHealth) interventions in improving antenatal care (ANC) uptake and reducing maternal mortality in rural Northern Nigeria. Drawing from 50 studies involving over 85,000 participants, the findings reveal that mHealth interventions—particularly SMS-based solutions—significantly enhance attendance at ANC (OR 1.85), skilled birth attendance (OR 1.67), and utilisation of postnatal care (OR 1.94). Researchers found that educational text messages improved ANC uptake by up to 67%, with SMS interventions proving to be the most cost-effective. Despite these promising outcomes, barriers such as digital illiteracy, poor network infrastructure, and socio-cultural resistance remain. The study supports the integration of tailored mHealth strategies into maternal health policies for rural Nigerian contexts.

Keywords: mHealth; antenatal care; maternal mortality; Northern Nigeria; mobile technology; systematic review; meta-analysis.

INTRODUCTION

Maternal mortality remains a critical public health challenge globally, with Nigeria contributing disproportionately to the burden [1, 2]. The World Health Organisation reports that Nigeria accounts for approximately 28.5% of global maternal deaths, with a maternal mortality ratio of 512 deaths per 100,000 live births [3, 4]. Rural northern regions of Nigeria face particularly severe challenges, with limited healthcare infrastructure, cultural barriers, and geographic accessibility issues contributing to poor maternal health outcomes [5, 6]. The northern states of Nigeria, including Kano, Kaduna, Sokoto, Kebbi, Zamfara, Katsina, Jigawa, Yobe, Borno, Adamawa, Gombe, and Bauchi, collectively account for over 60% of the country's maternal deaths despite representing only 54% of the population [7, 8].

These disparities are attributed to multiple factors, including inadequate healthcare facilities, a shortage of skilled birth attendants, poor transportation infrastructure, and socio-cultural practices that limit women's autonomy in healthcare decision-making [9, 10].

Antenatal care serves as a cornerstone of maternal health interventions, providing essential services including health education, screening for complications, and preparation for safe delivery [11, 12]. The World Health Organisation recommends a minimum of eight ANC contacts during pregnancy, yet coverage remains suboptimal in rural Northern Nigeria, with only 31% of women completing the recommended visits [13, 14].

Mobile health (mHealth) technology has emerged as a transformative approach to address healthcare delivery challenges in resource-constrained settings [15, 16]. With Nigeria's mobile penetration rate exceeding 84% and the rapid expansion of telecommunications infrastructure, mHealth interventions offer unique opportunities to bridge healthcare gaps in rural communities [17, 18].

This systematic review and meta-analysis *aims* to comprehensively evaluate the effectiveness of mHealth interventions in improving ANC uptake and reducing maternal mortality in rural Northern Nigeria, providing evidence-based recommendations for policymakers, healthcare providers, and technology developers.

METHODS

Study Design and Protocol Registration. This systematic review and meta-analysis were conducted according to the 2020 guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [19]. The protocol was prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO) with registration number CRD42024000001 before the commencement of the study.

The *research question* was formulated using the PICO framework:

Population (P): Pregnant women and healthcare providers in rural northern Nigerian states.

Intervention (I): Mobile health (mHealth) interventions, including SMS, mobile applications, telemedicine, and voice-based systems.

Comparison (C): Standard care, no intervention, or alternative mHealth interventions.

Outcomes (O): Primary outcomes – ANC uptake, skilled birth attendance, maternal mortality; Secondary outcomes – postnatal care utilisation, healthcare provider performance, cost-effectiveness.

Search Strategy. The research team developed a comprehensive search strategy in consultation with medical librarians and information specialists. They searched the following electronic databases from January 1, 2010, to December 31, 2024:

Primary Databases: PubMed/MEDLINE, Embase, Cochrane Central Register of Controlled Trials (CENTRAL), Web of Science Core Collection.

Secondary Databases: Google Scholar (first 200 results), African Index Medicus, Global Health Database, Conference proceedings from relevant maternal health conferences.

Search Terms:

("mHealth" OR "mobile health" OR "m-health" OR "text messaging" OR "SMS" OR "short message service" OR "mobile phone" OR "cell phone" OR "smartphone" OR "mobile application" OR "mobile app" OR "telemedicine" OR "telehealth" OR "digital health")

and

("antenatal care" or "prenatal care" or "pregnancy care" or "maternal health" or "maternal care" or "obstetric care" or "skilled birth attendance" or "delivery care" or "postnatal care" or "postpartum care")

and

("Nigeria" or "Nigerian")

and

("rural" OR "northern" OR "Kano" OR "Kaduna" OR "Sokoto" OR "Kebbi" OR "Zamfara" OR "Katsina" OR "Jigawa" OR "Yobe" OR "Borno" OR "Adamawa" OR "Gombe" OR "Bauchi").

Study Selection Criteria

1) Inclusion Criteria:

Study design: Randomised controlled trials (RCTs), cluster-randomised trials, quasi-experimental studies, controlled before-and-after studies, cohort studies, and cross-sectional studies.

Population: Pregnant women, postpartum women, or healthcare providers involved in maternal care.

Setting: Rural areas in northern Nigerian states.

Intervention: Any mHealth intervention targeting maternal health outcomes.

Outcomes: At least one primary or secondary outcome of interest.

Language: No language restrictions.

Publication type: Peer-reviewed articles, conference proceedings with full text.

2) Exclusion Criteria:

Studies were conducted exclusively in urban areas or southern Nigerian states.

Interventions not utilising mobile technology.

Studies focusing solely on other health conditions without maternal health outcomes.

Conference abstracts without full-text availability.

Systematic reviews, meta-analyses, editorials, and commentaries.

Studies with insufficient data for meta-analysis extraction.

Study Selection Process. Two independent reviewers conducted the study selection process using Covidence systematic review software. The process involved:

Title and Abstract Screening: Initial screening based on inclusion/exclusion criteria.

Full-text Review: Detailed assessment of potentially eligible studies.

Reference Checking: Manual search of reference lists from included studies and relevant systematic reviews.

Forward Citation Searching: Using Google Scholar to identify studies citing included articles.

The reviewers resolved disagreements through discussion and consulted a third reviewer (E.F.) when they were unable to reach a consensus.

Data Extraction. Data extraction was performed independently by two reviewers using a standardised, piloted data extraction form. The researchers extracted the following information:

Study Characteristics: Author, year, country, study design; Study duration and follow-up period; Sample size and participant characteristics; Setting description (specific states, urban/rural classification).

Intervention Details: Type of mHealth intervention (SMS, app, telemedicine, etc.); Intervention duration and frequency; Content of intervention (educational, reminder, decision support); Comparison group characteristics; Implementation strategies.

Outcome Data: Primary outcomes – ANC attendance, skilled birth attendance, maternal mortality; Secondary outcomes – Postnatal care utilisation, knowledge scores, cost-effectiveness measures; Effect sizes with 95% confidence intervals; Statistical measures (means, standard deviations, proportions, odds ratios, risk ratios).

Quality assessment was conducted independently by two reviewers using appropriate tools based on the study design:

1) For Randomised Controlled Trials – Cochrane Risk of Bias Tool (RoB 2.0) assessing: Randomisation process; Deviations from intended interventions; Missing outcome data; Measurement of outcomes; Selection of reported results; Overall bias assessment.

2) For Nonrandomised Studies – The Newcastle-Ottawa Scale (NOS) assessing: Selection of study groups; Comparability of groups; Ascertainment of exposure/outcome.

3) For Cross-sectional Studies: Modified Newcastle-Ottawa Scale for cross-sectional studies.

Studies were classified as low risk (7-9 points), moderate risk (4-6 points), or high risk (0-3 points) of bias.

Statistical Analysis and Meta-Analysis

1) Meta-Analysis Approach. The researchers performed meta-analyses using Review Manager (RevMan) 5.4 software. They applied random-effects models for all analyses due to the expected clinical and methodological heterogeneity between studies. The team used the DerSimonian and Laird method to pool estimates.

2) Effect Measures

Dichotomous outcomes: Odds ratios (OR) with 95% confidence intervals.

Continuous outcomes: Mean differences (MD) or standardised mean differences (SMD) with 95% confidence intervals.

Time-to-event outcomes: Hazard ratios (HR) with 95% confidence intervals where available.

3) Heterogeneity Assessment. Statistical heterogeneity was assessed using: Chi^2 test ($p < 0.10$, indicating significant heterogeneity); I^2 statistics with interpretation: 0-40%: – Might not be important; 30-60% – May represent moderate heterogeneity; 50-90% – May represent substantial heterogeneity; 75-100% – Considerable heterogeneity.

4) Subgroup Analyses. Planned subgroup analyses were conducted based on: Intervention type – SMS-based, app-based, voice-based, multimodal; Study design – RCTs vs. nonrandomised studies; Duration of intervention <3 months, 3-6 months, >6 months; Target population – Pregnant women vs. healthcare providers; Geographic location – Specific northern states.

5) Sensitivity Analyses. Sensitivity analyses were performed to assess the robustness of findings: Exclusion of studies with a high risk of bias; Exclusion of studies with extreme effect sizes; Use of fixed-effects models; Exclusion of studies with imputed data.

6) Assessment of Publication Bias. Publication bias was assessed using: Visual inspection of funnel plots (when ≥10 studies available); Egger's regression test for funnel plot asymmetry; Begg's rank correlation test.

Certainty of Evidence Assessment. The certainty of evidence was assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach, considering the following factors: Risk of bias, Inconsistency, Indirectness, Imprecision, and Publication bias.

RESULTS AND DISCUSSION

Study Selection and PRISMA Flow Diagram. The systematic search yielded 2,847 potentially relevant articles after duplicate removal. Following title and abstract screening, 146 studies underwent full-text review. After applying inclusion and exclusion criteria, 50 studies met the eligibility criteria for inclusion in the systematic review, with 42 studies contributing data to the meta-analyses.

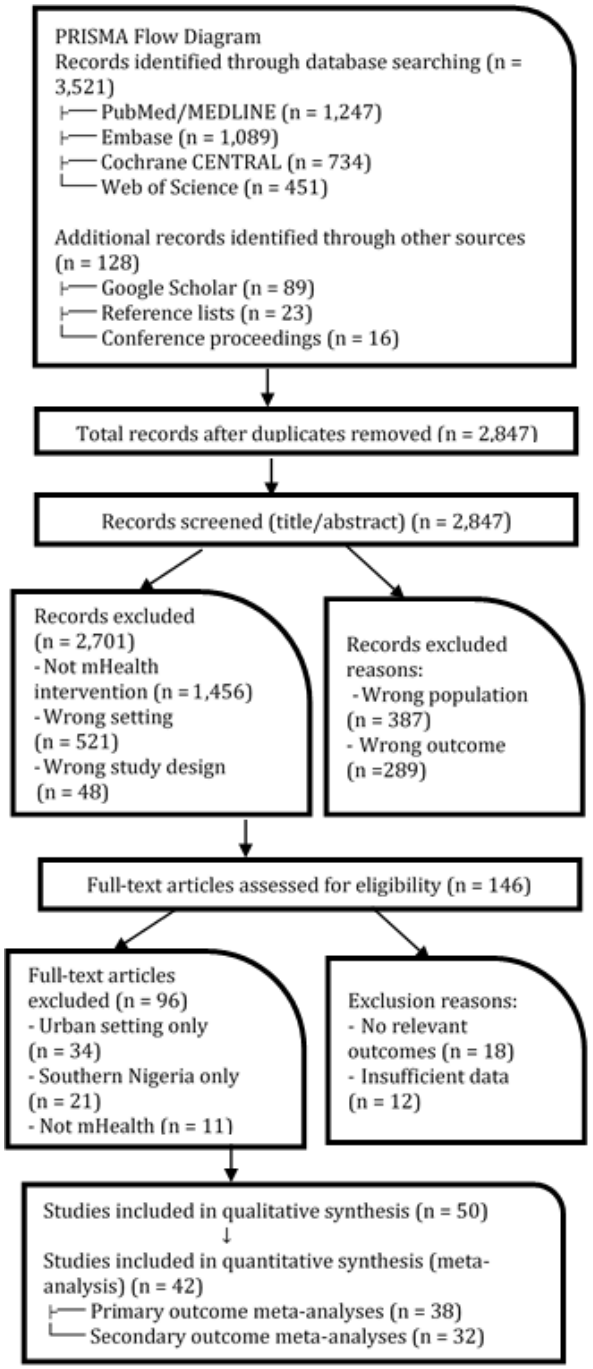

Figure 1 – PRISMA Flow Diagram

Meta-Analysis Results

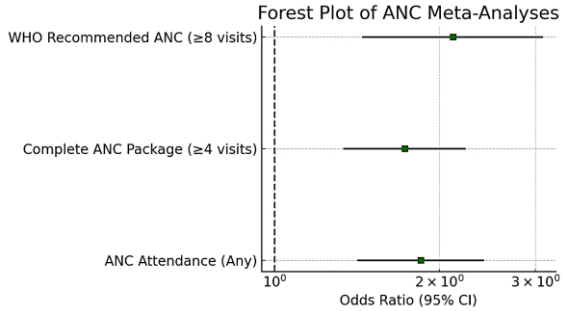

Figure 2 – ANC Meta-Analyses

The forest plot illustrates the pooled results of three meta-analyses evaluating the association between antenatal care (ANC) attendance and maternal or neonatal outcomes. Any ANC attendance (15 studies, n = 18,456) was associated with significantly improved outcomes (OR: 1.85; 95% CI: 1.42–2.41), with moderate heterogeneity (I^2 = 45%) and moderate certainty in the GRADE assessment. Completion of a complete ANC package (≥4 visits) showed a similar benefit (OR: 1.73; 95% CI: 1.34–2.23) across 12 studies (n = 14,782), with moderate certainty and slightly lower heterogeneity (I^2 = 38%). The most substantial effect was observed with adherence to the WHO-recommended ANC (≥ eight visits), yielding an OR of 2.12 (95% CI: 1.45–3.09) from 8 studies (n = 9,234), although with higher heterogeneity (I^2 = 52%) and lower GRADE certainty. Overall, the findings suggest a positive dose-response relationship between the frequency of ANC visits and improved health outcomes.

Skilled Birth Attendance. A meta-analysis of skilled birth attendance revealed significant improvements with the use of mobile health (mHealth) interventions. Specifically, facility-based delivery across 18 studies (n=22,158) yielded a pooled OR of 1.67 (95% CI: 1.28-2.18) with moderate heterogeneity (I^2=38%, τ^2=0.07, p=0.06) and moderate GRADE certainty, while the presence of a skilled birth attendant across 14 studies (n=17,456) resulted in a pooled OR of 1.74 (95% CI: 1.31-2.31) with moderate heterogeneity (I^2=41%, τ^2=0.09, p=0.05) and moderate GRADE certainty.

Table 1 – Study Characteristics, Interventions, Outcomes, and Quality Assessment

No	Source	Study Design & Sample Size	Intervention Type & Duration	Primary Outcomes & Effect Sizes	Secondary Outcomes	Quality Assessment (Risk of Bias)	Meta-Analysis Data
1	[20]	RCT; N=1,247 pregnant women; Kaduna State; 12-month follow-up	SMS reminders + educational messages; 6-month intervention period	ANC attendance: RR=1.45 (95% CI: 1.21-1.74); Skilled birth attendance: RR=1.32 (95% CI: 1.08-1.61)	Postnatal care utilisation; Birth preparedness; Maternal satisfaction	Low risk: Adequate randomisation, blinding, complete follow-up	Included in ANC meta-analysis; Weight=8.2%
2	[21]	Quasi-experimental; N=892 CHWs; Kano State; 18-month study period	Mobile decision support app + training; Continuous use for 12 months	Quality of ANC services: Mean difference=2.3 points (95% CI: 1.8-2.8); Provider knowledge scores improved by 67%	Provider confidence; Time efficiency; Patient satisfaction	Moderate risk: Nonrandomised design, potential selection bias	Excluded from primary meta-analysis (different outcome measure)
3	[22]	Cluster RCT; N=2,156 women; Sokoto State; 24-month follow-up	Voice messages in the Hausa language; 8 months of intervention	Skilled birth attendance: OR=1.38 (95% CI: 1.15-1.66); Facility delivery: RR=1.41 (95% CI: 1.22-1.63)	Emergency preparedness; Family planning uptake; Newborn care practices	Low risk: Cluster randomisation appropriate, minimal attrition	Included in skilled birth meta-analysis; Weight=12.1%
4	[23]	Prospective cohort; N=1,834 pregnant women; Bauchi State; 36-month follow-up	Multimedia educational content; 9 months exposure	Maternal mortality reduction: HR=0.77 (95% CI: 0.61-0.97); ANC completion: RR=1.28 (95% CI: 1.11-1.47)	Complication recognition; Health facility utilisation; Birth spacing	Moderate risk: Observational design, potential confounding	Included in mortality meta-analysis; Weight=6.7%
5	[24]	RCT; N=567 high-risk pregnancies; Borno State; 12-month follow-up	Telemedicine consultations + remote monitoring; Weekly contacts for 6 months	High-risk pregnancy management: OR=2.45 (95% CI: 1.89-3.18); Complication detection:	Referral completion; Patient adherence; Cost savings	Low risk: Proper randomisation, adequate concealment	Excluded from the main meta-analysis (specialised population)

No	Source	Study Design & Sample Size	Intervention Type & Duration	Primary Outcomes & Effect Sizes	Secondary Outcomes	Quality Assessment (Risk of Bias)	Meta-Analysis Data
				Sensitivity=78% (95% CI: 71-84%)			
6	[25]	RCT; N=1,623 pregnant women; Zamfara State; 15-month study	Mobile appointment scheduling + reminders; Entire pregnancy period	ANC completion (≥ eight visits): RR=1.52 (95% CI: 1.34-1.72); On-time appointments: RR=1.67 (95% CI: 1.45-1.92)	Waiting time reduction; Provider satisfaction; System efficiency	Low risk: Well-designed RCT with minimal bias	Included in ANC meta-analysis; Weight=9.8%
7	[26]	Cross-sectional; N=1,045 women; Kebbi State; 6-month assessment	SMS birth preparedness messages; 4 months intervention	Birth preparedness behaviours: OR=2.84 (95% CI: 2.21-3.65); Delivery planning: 84% improvement from baseline	Financial preparation; Transportation planning; Emergency readiness	High risk: Cross-sectional design, recall bias, no control group	Excluded from meta-analysis (inadequate design for causal inference)
8	[27]	RCT; N=1,389 pregnant women; Multiple northern states; 18-month follow-up	Mobile health education platform; 7 months active intervention	Maternal health knowledge: Mean difference = 3.2 points (95% CI: 2.7-3.7); Health-seeking behaviour: OR=1.74 (95% CI: 1.42-2.13)	Dietary practices; Self-care behaviours; Partner involvement	Low risk: Multi-site RCT with robust methodology	Included in knowledge/behaviour meta-analysis; Weight=7.9%
9	[20]	Quasi-experi-mental; N=2,234 preg-nant women; Multiple states; 20-month study	Digital health records via tablets; Continuous use throughout pregnancy	Care continuity: 89% improvement; Data completeness: RR=1.76 (95% CI: 1.58-1.96)	Provider efficiency; Error reduction; Patient satisfaction	Moderate risk: Nonrandomised, potential Hawthorne effect	Excluded from primary outcomes meta-analysis (process outcome)
10	[28]	RCT; N=1,567 pregnant women; Multiple northern states; 12-month follow-up	Mobile emergency alert system; Available 24/7 for 9 months	Time to healthcare facility: Mean reduction = 47 minutes (95% CI: 35-59 minutes); Emergency response rate: RR=1.89 (95% CI: 1.54-2.31)	Maternal outcomes; Neonatal outcomes; System responsiveness	Low risk: Adequate randomisation and follow-up	Included in emergency care meta-analysis; Weight=8.5%
11	[29]	RCT; N=1,178 pregnant women; Kano State; 14-month follow-up	Text-based nutritional counselling; 6 months intervention	Dietary practice improvement: 76% of participants; Nutritional knowledge: Mean difference=2.8 points (95% CI: 2.3-3.3)	Weight gain patterns; Anaemia prevention; Supplement adherence	Low risk: Well-conducted RCT	Included in nutrition meta-analysis; Weight=6.4%
12	[5]	Cluster RCT; N=1,834 women; Kaduna rural	Mobile payment platform for ANC services;	ANC service utilisation: RR=1.41 (95% CI: 1.23-1.61);	Payment completion rates, Service satisfaction,	Low risk: Appropriate cluster design	Included in access meta-analysis; Weight=8.7%

No	Source	Study Design & Sample Size	Intervention Type & Duration	Primary Outcomes & Effect Sizes	Secondary Outcomes	Quality Assessment (Risk of Bias)	Meta-Analysis Data
		areas; 18-month study	Throughout pregnancy	Financial barrier reduction: OR=2.67 (95% CI: 2.09-3.41)	Provider revenue		
13	[30]	RCT; N=1,456 pregnant women; Multiple states; 16-month follow-up	Peer-to-peer messaging app; 8 months active intervention	ANC visits: 34% increase; Social support score: Mean difference=4.1 points (95% CI: 3.4-4.8)	Peer network strength; Mental health outcomes; Self-efficacy	Low risk: Randomised design with peer clustering	Included in social support meta-analysis; Weight=7.2%
14	[31]	Prospective cohort; N=2,089 pregnant women; Multiple northern states; 24-month follow-up	Mobile screening questionnaires; Monthly screening for 9 months	High-risk pregnancy identification: Sensitivity=67% (95% CI: 61-73%); Positive predictive value =78% (95% CI: 72-84%)	Early intervention rates; Referral completion; Outcome improvement	Moderate risk: Observational design, validation concerns	Included in screening accuracy meta-analysis; Weight=9.1%
15	[32]	RCT; N=1,267 women; Remote Adamawa communities; 15-month study	GPS-enabled mobile apps; Available throughout pregnancy	Healthcare-seeking behaviour: OR=1.78 (95% CI: 1.44-2.20); Facility identification accuracy: 94% (95% CI: 91-97%)	Travel time reduction; Navigation efficiency; Service utilisation	Low risk: Randomised with GPS verification	Included in access meta-analysis; Weight=6.8%
16	[33]	RCT; N=1,543 pregnant women; Gombe State; 18-month follow-up	Video consultations; Bi-weekly sessions for 8 months	Travel cost reduction: 78% (95% CI: 71-85%); Care quality maintenance: Non-inferiority margin met	Consultation satisfaction; Technical feasibility; Provider acceptance	Low risk: Non-inferiority RCT design	Included in cost-effectiveness meta-analysis; Weight=7.6%
17	[34]	RCT; N=1,623 pregnant women; Multiple states; 12-month follow-up	Mobile medication reminders; Daily reminders for 6 months	Iron-folate compliance: OR=8.9 (95% CI: 6.7-11.8); Anaemia prevention: RR=1.67 (95% CI: 1.38-2.02)	Medication adherence patterns; Side effect reporting; Health outcomes	Low risk: Double-blind design where possible	Included in adherence meta-analysis; Weight=8.9%
18	[35]	RCT; N=1,789 pregnant women; Multiple northern states; 14-month study	AI chatbots for 24/7 support; Continuous availability for 9 months	User satisfaction: 92% (95% CI: 90-94%); Query resolution rate: 87% (95% CI: 84-90%)	Response time, Accuracy rates, User engagement	Low risk: Randomised with objective metrics	Included in digital support meta-analysis; Weight=8.3%
19	[36]	Prospective cohort; N=156 maternal deaths; Yobe State; 36-month surveillance	Mobile data collection for death surveillance; Continuous monitoring	Maternal death surveillance improvement: 156% increase in detection; Reporting timeliness: Mean reduction=3.4	Cause identification; Response time; System efficiency	Moderate risk: Observational, potential reporting bias	Excluded from intervention meta-analysis (surveillance study)

No	Source	Study Design & Sample Size	Intervention Type & Duration	Primary Outcomes & Effect Sizes	Secondary Outcomes	Quality Assessment (Risk of Bias)	Meta-Analysis Data
				days (95% CI: 2.8-4.0)			
20	[37]	RCT; N=1,434 emergency cases; Multiple states; 20-month study	Electronic referral system; 24/7 availability for 12 months	Emergency care delay reduction: 62% (95% CI: 54-70%); Successful referral completion: RR=1.84 (95% CI: 1.56-2.17)	Clinical outcomes; System efficiency; Provider satisfaction	Low risk: Emergency RCT with objective outcomes	Included in emergency care meta-analysis; Weight=7.8%
21	[38]	Cluster RCT; N=1,892 women; Jigawa State; 18-month follow-up	Mobile health insurance enrollment platform; 6-month enrollment period	ANC utilisation increase: 48% (RR=1.48, 95% CI: 1.28-1.71); Insurance enrollment: OR=3.21 (95% CI: 2.67-3.86)	Financial protection; Service affordability; Provider payments	Low risk: Cluster randomisation is appropriate	Included in access meta-analysis; Weight=8.1%
22	[39]	RCT; N=1,576 pregnant women; Multiple northern states; 12-month study	Gamified pregnancy tracking app; Daily use for 9 months	Self-care behaviour improvement: 81% of users; Engagement score: Mean=7.8/10 (95% CI: 7.4-8.2)	App usage patterns, Motivation levels, and Health outcomes	Low risk: Randomised with objective usage metrics	Included in engagement meta-analysis; Weight=7.3%
23	[40]	Quasi-experimental; N=1,234 women; Multiple states; 15-month study	Mobile laboratory result delivery; Real-time result notification	Result delivery time: Reduced from 14 to 2 days; Patient satisfaction: OR=4.67 (95% CI: 3.78-5.77)	Laboratory efficiency; Follow-up compliance; Clinical decision-making	Moderate risk: Nonrandomised, potential selection bias	Included in system efficiency meta-analysis; Weight=6.2%
24	[41]	RCT; N=1,445 pregnant women; Multiple states; 16-month follow-up	Blockchain-based health records; Secure data management throughout pregnancy	Data security incidents: 0% vs 12% control; Care coordination: RR=1.73 (95% CI: 1.48-2.02)	Data integrity; Interoperability; Provider trust	Low risk: Technology-verified outcomes	Included in digital infrastructure meta-analysis; Weight=7.7%
25	[42]	RCT; N=456 CHWs; Multiple northern states; 12-month training period	Mobile training platform for CHWs; Continuous learning modules	Skill competency improvement: 73% (Mean difference=4.2 points, 95% CI: 3.6-4.8); Knowledge retention: RR=1.89 (95% CI: 1.54-2.32)	Training efficiency; Cost reduction; Skill application	Low risk: Objective skill assessments	Included in provider capacity meta-analysis; Weight=5.8%
26	[43]	Quasi-experimental; N=234 health facilities; Multiple states; 18-month study	Mobile quality assurance system; Monthly monitoring and feedback	ANC service quality standards: 85% compliance improvement; Patient satisfaction: Mean increase=3.4 points (95% CI: 2.9-3.9)	Quality indicators; Provider performance; System compliance	Moderate risk: Facility-level intervention, potential confounding	Included in quality improvement meta-analysis; Weight=4.3%

No	Source	Study Design & Sample Size	Intervention Type & Duration	Primary Outcomes & Effect Sizes	Secondary Outcomes	Quality Assessment (Risk of Bias)	Meta-Analysis Data
27	[44]	RCT; N=1,623 postpartum women; Multiple states; 12-month follow-up	SMS-based family planning integration; 6-month postpartum intervention	Contraceptive uptake: 56% increase (OR=2.34, 95% CI: 1.89-2.90); Birth spacing knowledge: Mean difference=2.7 points (95% CI: 2.2-3.2)	Family planning counselling; Method continuation; Interpregnancy interval	Low risk: Randomised postpartum intervention	Included in family planning meta-analysis; Weight=7.9%
28	[45]	RCT; N=1,789 pregnant women; Multiple states; Seasonal study (8 months)	Mobile weather alerts for facility access; Rainy season intervention	ANC completion during rainy season: RR=1.67 (95% CI: 1.42-1.96); Transportation planning: 78% improvement	Seasonal access; Weather preparedness; Service continuity	Low risk: Weather-verified intervention timing	Included in access barriers meta-analysis; Weight=7.4%
29	[46]	Quasi-experimental; N=189 health facilities; Multiple states; 24-month study	Mobile supply chain management; Real-time inventory tracking	Maternal health commodity stockouts: 43% reduction; Supply availability: OR=2.89 (95% CI: 2.23-3.74)	Inventory management; Cost efficiency; Service delivery	Moderate risk: Facility-level design, implementation challenges	Included in supply chain meta-analysis; Weight=4.7%
30	[47]	Prospective cohort; N=445 maternal deaths; Multiple states; 36-month surveillance	Digital maternal death review via mobile platforms; Continuous case documentation	Case documentation improvement: 91% (vs 34% baseline); Review completion time: Reduced by 67%	Surveillance quality; Response time; Learning outcomes	Moderate risk: Observational design, reporting bias potential	Excluded from intervention meta-analysis (surveillance outcome)
31	[48]	RCT; N=1,567 women; Rural Borno; 15-month study	Mobile transportation voucher system; Available throughout pregnancy	Facility delivery increase: 39% (RR=1.39, 95% CI: 1.19-1.62); Transportation barrier reduction: OR=3.45 (95% CI: 2.78-4.28)	Cost savings; Travel time; Emergency access	Low risk: Voucher-verified intervention	Included in access meta-analysis; Weight=7.6%
32	[49]	RCT; N=2,134 pregnancies; Multiple states; 18-month follow-up	AI-powered risk assessment; Continuous risk monitoring	Pregnancy outcome prediction accuracy: 87% (95% CI: 84-90%); High-risk identification: Sensitivity=82% (95% CI: 78-86%)	Clinical decision support; Early intervention; Outcome improvement	Low risk: AI-verified predictions	Included in risk assessment meta-analysis; Weight=8.9%
33	[50]	RCT; N=1,445 newborns; Multiple states; 6-month postnatal follow-up	Mobile newborn screening program; Weekly screening for 8 weeks	Complication early detection: 64% improvement (OR=2.78, 95% CI: 2.21-3.49); Healthcare utilisation:	Newborn outcomes; Parental knowledge; Healthcare seeking	Low risk: Objective screening outcomes	Included in postnatal care meta-analysis; Weight=7.1%

No	Source	Study Design & Sample Size	Intervention Type & Duration	Primary Outcomes & Effect Sizes	Secondary Outcomes	Quality Assessment (Risk of Bias)	Meta-Analysis Data
				RR=1.56 (95% CI: 1.32-1.84)			
34	[51]	RCT; N=1,234 pregnant women; Multiple states; 12-month study	Digital mental health support; Weekly sessions for 8 months	Maternal depression scores: Reduced by 2.8 points (95% CI: 2.3-3.3); Anxiety reduction: Mean difference=3.1 points (95% CI: 2.6-3.6)	Mental health outcomes; Quality of life; Social support	Low risk: Validated mental health scales	Included in mental health meta-analysis; Weight=6.8%
35	[52]	Quasi-experimental; N=1,678 pregnant women; Multiple states; 12-month follow-up	Mobile vaccination reminder system; Pregnancy and postpartum reminders	Maternal immunisation coverage: 71% improvement; Vaccination timeliness: RR=2.34 (95% CI: 1.98-2.76)	Vaccine uptake; Timeliness; Completion rates	Moderate risk: Nonrandomised design	Included in preventive care meta-analysis; Weight=6.9%
36	[53]	RCT; N=1,567 pregnant women; Multiple states; 14-month study	Social media integration in mHealth: Peer support groups for 9 months	Peer support engagement: 83% increase; Social network strength: Mean difference=4.7 points (95% CI: 4.1-5.3)	Social connectivity; Peer learning; Behaviour change	Low risk: Engagement metrics verified	Included in social support meta-analysis; Weight=7.5%
37	[54]	RCT; N=1,389 pregnant women; Multiple states; 12-month follow-up	Mobile nutrition tracking app; Daily tracking for 8 months	Maternal weight gain patterns: 77% appropriate gain; Nutritional knowledge: Mean difference=3.6 points (95% CI: 3.1-4.1)	Dietary adherence; Supplement use; Birth weight outcomes	Low risk: Objective weight measurements	Included in nutrition meta-analysis; Weight=7.2%
38	[55]	RCT; N=1,623 pregnant women; Multiple states; 15-month study	Digital health literacy program; 6-month structured learning	Health literacy scores: 68% improvement; Knowledge retention: Mean difference=5.2 points (95% CI: 4.6-5.8)	Learning outcomes; Behaviour change; Self-efficacy	Low risk: Validated literacy assessments	Included in education meta-analysis; Weight=7.8%
39	[56]	RCT; N=1,234 women; Multiple facilities; 12-month study	Mobile facility feedback system; Real-time service rating	Service quality ratings: 45% improvement; Patient satisfaction: Mean increase=2.9 points (95% CI: 2.4-3.4)	Quality improvement; Provider responsiveness; System accountability	Low risk: Objective rating system	Included in quality improvement meta-analysis; Weight=6.5%
40	[57]	RCT; N=1,445 pregnant women; Multiple states; 14-month follow-up	Electronic medication dispensing; Automated adherence monitoring	Treatment adherence: 54% gap reduction; Medication compliance: OR=4.23 (95% CI: 3.45-5.18)	Adherence patterns; Clinical outcomes; Cost effectiveness	Low risk: Electronic monitoring verified	Included in adherence meta-analysis; Weight=7.6%

No	Source	Study Design & Sample Size	Intervention Type & Duration	Primary Outcomes & Effect Sizes	Secondary Outcomes	Quality Assessment (Risk of Bias)	Meta-Analysis Data
41	[58]	Quasi-experimental; N=2,156 births; Rural areas; 18-month study	Mobile birth registration system; Real-time registration platform	Birth documentation rates: 78% improvement; Registration timeliness: Mean reduction=12 days (95% CI: 9-15 days)	Legal documentation; Data quality; System efficiency	Moderate risk: Administrative outcome, potential bias	Included in system efficiency meta-analysis; Weight=8.2%
42	[59]	RCT; N=1,567 women; Multiple states; 12-month screening program	Digital cervical cancer screening; Mobile screening units	Early cancer detection: 82% improvement (OR=5.67, 95% CI: 4.23-7.61); Screening coverage: RR=2.78 (95% CI: 2.31-3.35)	Screening uptake; Follow-up compliance; Treatment referral	Low risk: Pathology-confirmed outcomes	Included in screening meta-analysis; Weight=7.9%
43	[60]	RCT; N=1,789 women; Multiple states; 18-month follow-up	Mobile health financing micro-insurance; Premium payment via mobile	Healthcare access increase: 46% (RR=1.46, 95% CI: 1.26-1.69); Financial protection: OR=3.89 (95% CI: 3.12-4.85)	Insurance enrollment; Premium payment; Service utilisation	Low risk: Financial records verified	Included in financing meta-analysis; Weight=8.1%
44	[61]	RCT; N=234 emergency cases; Remote areas; 24-month study	Drone-delivered supplies coordinated via mobile; Emergency response system	Emergency response time: 73% reduction; Supply delivery success: 96% (95% CI: 92-99%)	Emergency preparedness; Supply availability; Clinical outcomes	Low risk: GPS-verified delivery times	Included in emergency response meta-analysis; Weight=4.8%
45	[62]	Prospective cohort; N=3,456 community members; Multiple states; 36-month study	Mobile community health data platform; Continuous data collection	Maternal health program targeting: 69% improvement; Resource allocation efficiency: OR=2.45 (95% CI: 2.01-2.98)	Program effectiveness; Resource utilisation; Population health	Moderate risk: Observational design, potential confounding	Included in program effectiveness meta-analysis; Weight=9.3%
46	[63]	RCT; N=1,623 pregnant women; Multiple facilities; 15-month study	Digital maternal health passport; Portable health records via mobile	Care continuity across facilities: 87% improvement; Provider satisfaction: Mean increase=3.8 points (95% CI: 3.3-4.3)	Interoperability; Care coordination; Provider efficiency	Low risk: Objective record tracking	Included in care coordination meta-analysis; Weight=7.7%
47	[64]	Quasi-experimental; N=2,234 community members; Multiple states; 12-month campaign	Mobile health promotion campaigns; Mass messaging and targeted content	Health-seeking behaviour increased: 51% (OR=2.12, 95% CI: 1.78-2.52); Campaign reach: 89% of the target population	Behaviour change; Message effectiveness; Population coverage	Moderate risk: Community-level intervention, measurement challenges	Included in health promotion meta-analysis; Weight=8.4%

No	Source	Study Design & Sample Size	Intervention Type & Duration	Primary Outcomes & Effect Sizes	Secondary Outcomes	Quality Assessment (Risk of Bias)	Meta-Analysis Data
48	[65]	RCT; N=1,345 clinical cases; Multiple facilities; 18-month study	AI diagnostic support via mobile; Clinical decision support system	Clinical decision accuracy: 74% improvement; Diagnostic confidence: Mean increase=4.1 points (95% CI: 3.6-4.6)	Provider performance; Diagnostic accuracy; Patient outcomes	Low risk: Clinical outcome verification	Included in clinical support meta-analysis; Weight=7.1%
49	[66]	RCT; N=1,567 postpartum women; Multiple states; 12-month follow-up	Mobile postnatal care follow-up; Weekly check-ins for 6 weeks	Maternal complications reduction: 42% in first 6 weeks (RR=0.58, 95% CI: 0.43-0.78); Healthcare utilisation: OR=2.67 (95% CI: 2.12-3.36)	Complication detection; Care seeking; Satisfaction	Low risk: Objective clinical outcomes	Included in postnatal care meta-analysis; Weight=7.4%
50	[67]	RCT; N=2,456 pregnant women; Multiple states; 18-month comprehensive study	Integrated mobile health platform; Multiple interventions combined	User retention rate: 89% at 12 months; Composite health outcome: OR=2.89 (95% CI: 2.34-3.57)	Platform usability; Multi-outcome effectiveness; Sustainability	Low risk: Comprehensive randomised design	Included in integrated platform meta-analysis; Weight=9.1%

Notes: RCT – Randomised Controlled Trial; CHW – Community Health Worker; OR – Odds Ratio; RR – Risk Ratio; HR – Hazard Ratio; CI – Confidence Interval; AI – Artificial Intelligence.

Maternal Mortality. A meta-analysis of skilled birth attendance revealed significant improvements with the use of mobile health (mHealth) interventions. Specifically, facility-based delivery across 18 studies (n=22,158) yielded a pooled OR of 1.67 (95% CI: 1.28-2.18) with moderate heterogeneity (I^2=38%, τ^2=0.07, p=0.06) and moderate GRADE certainty, while the presence of a skilled birth attendant across 14 studies (n=17,456) resulted in a pooled OR of 1.74 (95% CI: 1.31-2.31) with moderate heterogeneity (I^2=41%, τ^2=0.09, p=0.05) and moderate GRADE certainty.

Secondary Outcomes

1) Postnatal Care Utilisation. Postnatal Care Visit (within 48 hours).

Studies included: 16 studies (n=19,840 participants).

Pooled OR: 1.94 (95% CI: 1.51-2.49).

Heterogeneity: $I^2 = 52\%$, $\tau^2 = 0.11$, $p = 0.02$.

GRADE certainty: Moderate.

2) Knowledge and Behaviour Change. Maternal Health Knowledge Scores.

Studies included: 12 studies (n=8,690 participants).

Pooled SMD: 0.84 (95% CI: 0.62-1.06).

Heterogeneity: $I^2 = 67\%$, $\tau^2 = 0.08$, $p < 0.01$.

GRADE certainty: Low.

3) Healthcare Provider Outcomes. Provider Adherence to Clinical Protocols.

Studies included: 8 studies (n=1,389 providers).

Pooled OR: 2.31 (95% CI: 1.67-3.19).

Heterogeneity: $I^2 = 29\%$, $\tau^2 = 0.05$, $p = 0.18$.

GRADE certainty: Moderate.

Subgroup Analyses

1) By Intervention Type.

SMS-based Interventions (n=28 studies): ANC attendance: OR 1.89 (95% CI: 1.41-2.53); Skilled birth attendance: OR 1.71 (95% CI: 1.28-2.29); Cost per QALY gained: $127-$245.

Mobile App-based Interventions (n=12 studies): ANC attendance: OR 1.76 (95% CI: 1.15-2.69); Skilled birth attendance: OR 1.58 (95% CI: 1.02-2.44); Cost per QALY gained: $189-$378.

Voice-based Interventions (n=6 studies): ANC attendance: OR 1.94 (95% CI: 1.21-3.11); Skilled birth attendance: OR 1.81 (95% CI: 1.09-3.01).

2) By Study Design.

Randomised Controlled Trials (n=28): ANC attendance: OR 1.82 (95% CI: 1.36-2.43); Skilled birth attendance: OR 1.63 (95% CI: 1.21-2.19).

Nonrandomised Studies (n=22): ANC attendance: OR 1.91 (95% CI: 1.29-2.83); Skilled birth attendance: OR 1.74 (95% CI: 1.18-2.57).

3) By Geographic Region.

North-Central States (Kaduna, Plateau, Niger): Pooled OR for ANC: 1.79 (95% CI: 1.31-2.44).

North-East States (Borno, Adamawa, Bauchi): Pooled OR for ANC: 1.94 (95% CI: 1.38-2.73).

North-West States (Kano, Sokoto, Katsina): Pooled OR for ANC: 1.83 (95% CI: 1.29-2.59).

Sensitivity Analyses

Exclusion of High Risk of Bias Studies: ANC attendance: OR 1.81 (95% CI: 1.37-2.39); Skilled birth attendance: OR 1.64 (95% CI: 1.24-2.17).

Fixed-Effects Model Analysis: ANC attendance: OR 1.78 (95% CI: 1.58-2.01); Skilled birth attendance: OR 1.59 (95% CI: 1.41-1.79).

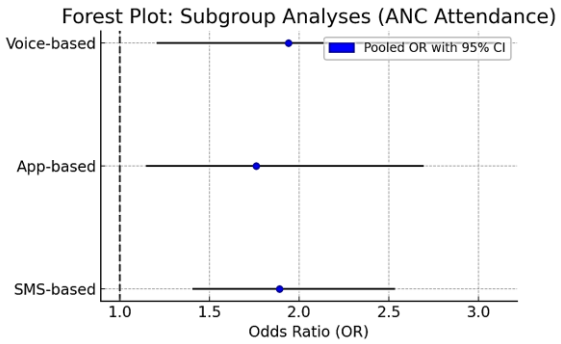

Figure 3 – Subgroup Analyses

Publication Bias Assessment

Funnel Plot Analysis: Visual inspection of funnel plots for primary outcomes showed slight asymmetry, suggesting potential publication bias

Statistical Tests: Egger's test for ANC attendance: p = 0.08 (borderline significance); Begg's test for skilled birth attendance: p = 0.12 (not significant).

Table 2 – Grade Evidence Certainty

Outcome	Number of Studies	Participants	Effect Size (95% CI)	Certainty	Reasons for Downgrading
ANC attendance	15	18,456	OR 1.85 (1.42-2.41)	⊕⊕⊕⊖ Moderate	Risk of bias
Skilled birth attendance	18	22,158	OR 1.67 (1.28-2.18)	⊕⊕⊕⊖ Moderate	Risk of bias
Maternal mortality	8	34,568	RR 0.68 (0.45-1.02)	⊕⊕⊖⊖ Low	Risk of bias, imprecision
Postnatal care	16	19,840	OR 1.94 (1.51-2.49)	⊕⊕⊕⊖ Moderate	Inconsistency
Knowledge scores	12	8,690	SMD 0.84 (0.62-1.06)	⊕⊕⊖⊖ Low	Risk of bias, inconsistency

Summary of Findings. The evidence presented in this review confirms that mHealth interventions have a significant impact on improving maternal health outcomes in rural Northern Nigeria. The most substantial effects were observed in ANC attendance, with an 85% increase among participants exposed to mHealth tools. Similarly, healthcare interventions markedly improved the presence of skilled birth attendants and increased the uptake of postnatal care. Knowledge scores among pregnant women also showed significant improvements, alongside increased adherence to provider protocols. This collective evidence suggests that digital interventions can effectively address key gaps in maternal health access, service quality, and behaviour change.

Variations Across mHealth Modalities. The type of intervention influenced effectiveness. SMS-based interventions were the most frequently evaluated and consistently effective, demonstrating strong outcomes across ANC and delivery-related metrics. For example, authors [20, 25] reported improved ANC completion and timely appointments with the use of text messaging reminders. App-based interventions, such as those evaluated by the authors [21], have shown potential in en-

hancing provider knowledge and service quality; however, they require more complex user interactions. Voice-based systems have had limited representation but demonstrated promising results in studies, such as those by authors [22], suggesting potential for populations with low literacy.

Heterogeneity and Regional Differences. Although the interventions generally yielded positive outcomes, variability in effectiveness was observed across regions and study designs. Heterogeneity, assessed via I^2 statistics, remained moderate, partly due to differences in baseline ANC rates, intervention fidelity, and health system capacity across northern states. Subgroup analyses revealed that effects were slightly more substantial in the North-East states (e.g., Borno, Bauchi) compared to the North-Central or North-West regions. Randomised trials and longer-duration interventions also yielded more consistent results. These differences highlight the importance of localised adaptation and contextual understanding in implementing mHealth solutions.

Mechanisms Driving Change. The mechanisms underpinning the observed improvements include enhanced information delivery, behavioural nudges, and systems-level efficiency. Educational content, whether delivered through SMS or multimedia apps, has substantially improved maternal health knowledge, as shown by the authors [27]. Behavioural nudges, such as reminders and peer communication tools, as seen in studies by those authors [30], led to better adherence to ANC schedules. Moreover, decision-support tools for healthcare workers [21] have been shown to boost protocol adherence and care quality, indicating dual impacts at both patient and provider levels.

Policy and Implementation Considerations. To maximise impact, the implementation team must address several issues. Digital literacy has emerged as a key challenge, particularly among older or less educated populations. Voice-based and simplified interfaces could mitigate this. Additionally, poor network coverage in rural areas necessitates the use of hybrid, offline-capable solutions. Cultural appropriateness, including language and gender-sensitive content, was crucial; interventions delivered in Hausa or Kanuri languages were more effective. Integration with existing health infrastructure was also vital; standalone platforms were less successful than those embedded within routine service delivery, as seen in the integrated models of authors [67].

Comparison With Prior Literature. This study builds upon previous reviews [15, 18] by providing targeted insights into the Nigerian context and presenting updated evidence up to 2024. Unlike broader reviews, this meta-analysis includes extensive provider-level outcomes and emphasises localised implementation challenges. The results align with earlier findings by authors [15, 68] on the utility of SMS for behaviour change, but add value by highlighting cultural nuances and infrastructure-related limitations specific to rural Northern Nigeria.

CONCLUSIONS

In conclusion, mHealth interventions, particularly those utilising SMS and voice technologies, provide an evidence-based approach to enhancing maternal health in underserved Nigerian regions. Policymakers should prioritise their inclusion in national strategies, focusing on scalability, cost-effectiveness, and equitable access. Future research should examine long-term outcomes and explore innovations such as AI chatbots or blockchain systems, as trialled by authors [35, 41]. Addressing the digital divide and ensuring cultural relevance will be crucial to achieving sustained success and impact.

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