SCIENTIFIC CULTURE
www.sci-cult.com

SCIENTIFIC CULTURE, Vol. 12, No. 1.1, (2026), pp. 1890-1904
Open Access. Online & Print

DOI: 10.5281/zenodo.11425238

INTEGRATING DIGITAL HEALTH AND CROSS-REGIONAL ANALYSIS IN EVALUATING BIHAR'S MATERNITY BENEFIT SCHEMES

Jyoti Kumari[1*] and Dr Ashish Ranjan Sinha[2]

[1]National Institute of Technology, Patna, Bihar, India, jyotik.phd20.hs@nitp.ac.in
[2]National Institute of Technology, Patna, Bihar, India, asish@nitp.ac.in
https://orcid.org/0000-0003-2868-5251

Received: 10/10/2025
Accepted: 10/11/2025

Corresponding author: Jyoti Kumari
Email: jyotik.phd20.hs@nitp.ac.in

ABSTRACT

Bihar lags on key maternal indicators despite national cash-transfer schemes. To test whether embedding a focused digital package within JSY/PMMVY delivery improves service uptake, processes, and early clinical outcomes versus a cross-state comparator, a quasi-experimental evaluation was conducted in six districts with baseline and 6–9-month follow-up among 2,400 beneficiaries and 520 workers. Difference-in-differences estimates favoured Bihar for ≥4 ANC (+12.8 pp), institutional delivery (+14.3 pp), PNC ≤48 h (+11.2 pp), and full immunisation by 12 months (+9.4 pp) (all p<0.001). Process gains were substantial, including improved scheme awareness (+17.6 pp), higher PMMVY enrollment (+10.5 pp), and shorter payment delays (−6.6 days). Early clinical changes were modest but statistically significant, with haemoglobin increasing by 0.3 g/dL and birthweight by 0.10 kg. Multilevel models yielded adjusted odds ratios of 2.34 for ANC4+, 2.67 for institutional delivery, and 2.12 for PNC ≤48 h, with approximately 39% of the total effect mediated by frontline performance in structural equation modeling. Equity analyses indicated attenuated gains among SC/ST and low-literacy groups. Integrating mHealth supports into scheme operations produced rapid, policy-relevant improvements with early clinical signals; scale-up should combine digital tools with equity safeguards and sustained follow-up to confirm durability and cost-effectiveness.

KEYWORDS: Maternal Health, Digital Health, Conditional Cash Transfer, PMMVY, Bihar, Quasi-Experimental.

1. INTRODUCTION

Maternal mortality and morbidity remain major public health priorities: an estimated 260,000 pregnancy-related deaths occurred globally in 2023, with large between-country and within-country disparities. [1]India has made substantial progress in reducing maternal mortality in recent decades, but gains are uneven across states; the Sample Registration System estimates reported a high Maternal Mortality Ratio in Bihar compared with the national average. [2]Key maternal health service indicators in Bihar remain below national targets— antenatal care (4+ visits), institutional delivery coverage, and antenatal anaemia prevalence continue to reflect persistent access and quality gaps. [3]–

I Maternal mortality and morbidity remain major public health priorities: an estimated 260,000 pregnancy-related deaths occurred globally in 2023, with large between-country and within-country disparities (Chakrabarti et al., 2021). India has made substantial progress in reducing maternal mortality in recent decades, but gains are uneven across states; the Sample Registration System estimates reported a high Maternal Mortality Ratio in Bihar compared with the national average (GSMA, 2021; Labrique et al., 2013). Key maternal health service indicators in Bihar remain below national targets-antenatal care (4+ visits), institutional delivery coverage, and antenatal anaemia prevalence continue to reflect persistent access and quality gaps (International Institute for Population Sciences [IIPS], 2021; Lee et al., 2016).

India's conditional maternity-benefit programs-notably Janani Suraksha Yojana (JSY) and Pradhan Mantri Matru Vandana Yojana (PMMVY)-have increased service uptake in several settings, but implementation bottlenecks and uneven impact persist, especially in low-performing states (International Institute for Population Sciences & ICF, 2022; Negandhi et al., 2016). Digital health tools (mHealth, automated reminders, and provider dashboards) have shown promise in improving maternal service use in low- and middle-income countries, but rigorous evidence on integrating digital interventions with national cash-transfer schemes in resource-constrained Indian states is limited (International Telecommunication Union [ITU], 2023). Recent global guidance emphasises digital public infrastructure, governance, and equity in digital health, including protections for data rights, inclusive design for low-literacy users, and evaluation standards for national scale-ups (Lim et al., 2010; International Telecommunication Union [ITU], 2023; World Health Organization [WHO], 2019). India's ongoing Ayushman Bharat Digital Mission (ABDM) positions registries (ABHA IDs), consented data exchange, and provider registries as core rails for maternal-child health programs (Ministry of Women and Child Development, 2017). Post-2023 policy circulars and status notes highlight state-level onboarding, consent management, and interoperability pilots relevant to JSY/PMMVY workflows (Office of the Registrar General & Census Commissioner, India, 2021). The evaluation aligns with these frameworks by (i) testing citizen-facing nudges (SMS/IVR) alongside worker dashboards, (ii) measuring governance/process outcomes (e.g., payment timeliness), and (iii) examining equity differentials across digital-literacy strata and SC/ST groups. Our cross-regional design, therefore, provides state-actionable evidence on how digital rails can augment conditional cash transfers in low-resource settings.

This study uses a mixed-methods, quasi-experimental, cross-regional design to evaluate the impact of integrating a package of digital health interventions with existing maternity-benefit schemes in Bihar, with Odisha as a comparison state, focusing on service utilisation, clinical outcomes, implementation fidelity, and equity (caste, rural/urban, frontline worker digital skills).

2. METHODS

2.1. Study Design and Setting

This research employs a novel mixed-methods, cross-regional comparative design that integrates quantitative evaluation, qualitative exploration, and digital health interventions (Maita et al., 2024). The study is a methodological breakthrough, as it brings together customary maternal health programme evaluation and digital health assessment and cross-regional learning models.

The research is conducted across two Indian states

- **Bihar (intervention state):** Accepts the digital health package.
- **Odisha (comparison state):** As the natural experiment comparison group, Odisha continues using the same Mamata processes.

There are three districts (one urban, one rural, and one mixed) per state that are purposely sampled to reflect the variation in socioeconomic and health systems. The districts have both urban wards and rural blocks, so that they are represented by different settings.

The study follows a three-phase quasi-experimental evaluation framework

Table 1: Table Caption.

Phase	Description	Key Activities
Phase 1: Baseline Assessment	Pre-intervention data collection	Domestic surveys, beneficiary profiling, and records on the practices of frontline workers.
Phase 2: Digital Intervention (Bihar only)	Deployment of mHealth innovations	- Automated SMS/IVR reminders for ANC visits, immunisations, and entitlements. - Mobile application for DEOs and Anganwadi workers to track beneficiaries. - Performance dashboards for managers.
Phase 3: Post-Intervention Evaluation	Measurement of intervention effects	Conducted again 6-9 months of implementation, and comparative analysis of results between Bihar and Odisha.

The qualitative approach is integrated in all these stages, whether it is focus group discussion with the beneficiaries, key informant interviews with managers and health workers. Such integration will lead to a better insight into the experience with both cash transfer schemes and the digital tools.

In order to be methodologically rigorous, the analyses are performed on a pre-registered protocol. Adaptive feedback processes (e.g., refinement of SMS content) are also part of the study to enhance intervention relevance in the process of implementation.

2.2. Participants and Eligibility Criteria

The population of the study was divided into two groups: maternal beneficiaries and frontline workers.

Maternal Beneficiaries We had registered about 2,400 women (1,200 per state) who were currently pregnant or had had a live birth within 12 months. The eligibility criteria were that the participants had the ages of 18 to 45 years, lived at least 6 months in the study area, and might have been enrolled in JSY/PMMVY schemes (e.g., low-income households, first or second childbirth). Women were not allowed if they had a severe impairment of cognition or if they were intending to move during the time of the study. Anganwadi Workers (AWWs) are the ones who input the data of the beneficiaries in Bihar. Entries are reviewed by lady supervisors and verified by the Child Development Project Officers (CDPOs) with the assistance of Data Entry Operators (DEOs) and sent to be approval. The nodal officer at the state level does final sanctioning. This is a multi-level process that helps in the verification and accountability.

Frontline Workers. We have also approached about 520 health and social service personnel within the study districts. This encompassed both Auxiliary Nurse Midwives (ANMs) and Accredited Social Health Activists (ASHAs) working in the primary health centres, mainly in Odisha, along with the number of Anganwadi workers (AWWs). These cadres constitute the frontline workforce that is critical in terms of the implementation of the schemes. Qualification criteria included one year of professional experience and informed consent.

2.3. Sampling Strategy and Sample Size Calculation

Our stratified random sampling design is a multi-stage stratified random sampling study to allow representative coverage of a variety of socioeconomic and health care systems. Samples are purposely chosen, and one district is mainly urban, one mixed, and one rural district is chosen in each state. This stratification will guarantee that both the urban-rural differentials and the caste- and service-delivery variations are adequately captured. In each of the chosen districts, primary sampling units are the Anganwadi clusters (in Bihar) and primary health centres (in Odisha). These facilities are then randomly sampled with the use of catchment villages. Appropriate households having maternal beneficiaries are also determined using health registers and systematic household listing to ensure that women who fit the criteria of the study are included. To the frontline workers, we have all the Auxiliary Nurse Midwives (ANMs), Accredited Social Health Activists (ASHAs), Anganwadi Workers (AWWs) and Data Entry Operators (DEOs) operating in the sampled clusters. This will provide sufficient representation of health as well as the ICDS cadres, which are at the core of scheme implementation.

The estimation of the sample size is based on the main outcome, the better utilisation of the ANC, which must occur in four or more ANC visits. Based on the NFHS-4 and with initial evidence available in Bihar, we take a baseline of full-ANC coverage at 65% and expect it to rise to 80% in the intervention. With 80% statistical power and a two-tailed $\alpha = 0.05$, the minimum required sample size per group is calculated as

$$n = [(Z_{\alpha/2} + Z_{\beta})^2 \times (p_1(1-p_1) + p_2(1-p_2))] / (p_1 - p_2)^2$$

Where:

- $Z_{\alpha/2} = 1.96$ (95% confidence level)

- Z_β = 0.84 (80% power)
- p_1 = 0.65 (baseline proportion)
- p_2 = 0.80 (target proportion)

Substituting values:

$n = [(1.96 + 0.84)^2 \times (0.65 \times 0.35 + 0.80 \times 0.20)] / (0.80 - 0.65)^2 = 234$ women per group.

The adjustments were made to consider clustering and possible non-response. The calculation of the sample size was done using a design effect (DEFF equivalent to 1.5) to capture intra-cluster correlation and an estimated non-response rate of 20 per cent to show that the required sample consisted of 281 women per group. Taking into account states and urban-rural strata (2 × 2), the ultimate target sample was increased to around 2,400 women.

In the case of frontline workers, clustering at the district level (interclass correlation coefficient, ICC = 0.05) and performance variability were added to the sample design. The 520-worker sample gives more than 80% statistical power to identify moderate effect sizes (i.e. differences in key outcomes of about 15-20 per cent) at the 95 per cent confidence level, and correctly models the hierarchical structure of the data.

2.4. Data Collection Procedures

Complex digital instruments are used in data collection to ensure the maximisation of accuracy, efficiency and real-time monitoring. Anganwadi Workers (AWWs) and Lady Supervisors (LSs) and Survey teams conduct their work together as they collect information with the help of beneficiaries, who were reached with the help of Child Development Project Officers (CDPOs). The questionnaires are given offline and then digitised. To make them more accessible, all instruments are provided in Hindi and Odia, and audio integration is provided to the participants with low literacy levels. The structured questionnaire addresses a very broad variety of areas, namely, demographic and socioeconomic variables, obstetric history, healthcare utilisation patterns, knowledge and participation in maternal benefit schemes, the use of digital tools and satisfaction with services. Important sections provide in-depth data on the antenatal care (quantity of visits, services, satisfaction), delivery (place, type, problems), child immunisation status, and the benefits of the JSY/PMMVY (timeliness, amounts, and delays). Clinical measurements involve clinical procedures and calibration of equipment by trained nurses using standardised procedures. These are haemoglobin levels by assessment using HemoCue to establish the prevalence of anaemia, blood pressure by use of digital blood pressure apparatus, and anthropometry of the mother (weight, height, and mid-upper arm circumference). Birth weight is taken out of oil wells where it is available. The online platform also has automated range and consistency checks to guarantee data reliability. The system in the intervention arm (Bihar) provides scheduled SMS/IVR messages in Hindi or the local dialect. The support of Data Entry Operators (DEOs) and Anganwadi workers tracks the progress of beneficiaries through a mobile application, and the logs of use (logins, sending messages, and interactions with beneficiaries) are automatically stored and analysed. Conversely, the participants of the Odisha ones are subject to structured interviews and do not receive any digital interventions, thus maintaining the natural experiment design. Tapes are gathered using semi-structured interviews and focus group discussions with the purposefully selected beneficiaries (enrolled and non-enrolled) and key stakeholders, such as CDPOs, health officials, and frontline workers. All the sessions are audio-taped, verbatim-transcribed, and undergo a thematic analysis process to come up with subtle assessments of the implementation issues and views of digital intervention.

2.5. Variables and Operational Definitions

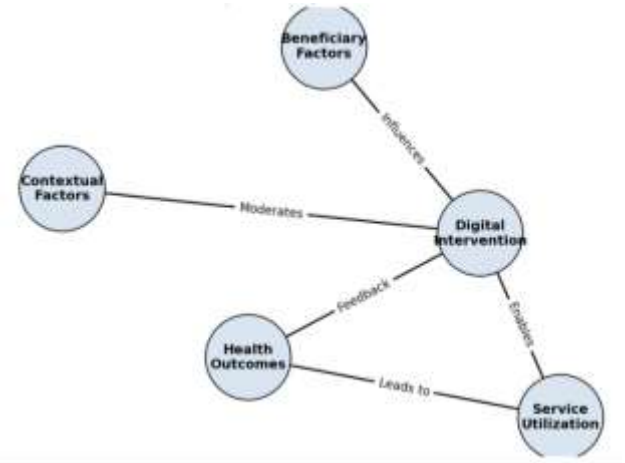

Figure 1: SEM-Style Conceptual Framework.

Figure 1 shows the proposed structural relationships among contextual factors, beneficiary characteristics, digital intervention processes, service utilisation, and health outcomes.

Primary Outcomes The primary outcomes focus on maternal service utilisation, measured through maternal self-report and corroborated with health cards when available. These include

a) Completion of ≥4 antenatal care (ANC) visits,
b) Institutional delivery,
c) Receipt of postnatal care (PNC) within 48

hours of delivery, and

d) Full immunisation of the child by 3 months of age.

These indicators are internationally recognised benchmarks of maternal and child health service quality.

Secondary Outcomes Objective measures of health status are found in secondary outcomes. These are levels of maternal haemoglobin (g/dL) and weight of birth (kg), and the complications during delivery (yes/no). Collectively, these clinical signs can offer strong data about the health status of mothers and their newborn babies, beyond service utilisation itself.

Intermediate and Process Variables Intermediate outcomes and process indicators are used to measure exposure to the digital interventions and the ability of frontline workers. SMS/reminder receipt (yes/no), mobile phone possession, and digital literacy are used to measure exposure by using an adapted 20-item Digital Health Literacy Scale (Norman & Skinner, 2006). Frontline worker capacity is measured in terms of a composite performance index that includes training completion, digital skills measures, and service quality measures.

Contextual Variables Contextual variables are socioeconomic status (wealth quintile, education level, caste category), place of residence (urban/rural), distance to the nearest health facility (GIS-mapped) and quality of governance of a district (measured with the help of standardised surveys). The addition of such variables enables equity-based analyses and provides the ability of multi-level modelling to consider much larger contextual effects on intervention efficacies.

2.6. Data Quality Assurance and Training

The study design incorporates several levels of quality control in order to make the data reliable. The digital data management system contains built-in range validations, internal consistency checks and error flags that are generated in real-time. In case of discrepancies, the same is promptly corrected by intervening with the supervisor, and then the enumerators are retrained accordingly. Also, the system keeps detailed audit logs, which allow tracking, checking and independent quality control over the entire data collection process.

2.7. Ethical Considerations and Approvals

All study participants are informed of the study purpose and the right to voluntarily withdraw from it without consequences, the nature is voluntary and confidentiality is ensured, and the study purpose is explained to them orally.

Considering the involvement of pregnant women and other vulnerable groups, it is particularly important to focus on the sensitivity, protection of privacy, and dignity of the participants. All the data collected is de-identified and encrypted, and stored in a secure place to maintain confidentiality. Occasionally, clinical assessments will uncover such urgent health conditions as severe anaemia or hypertension. In this situation, they are immediately referred to relevant medical centres to protect their health. Monitoring is also enhanced by the presence of the independent Data Safety Monitoring Board that performs a systematic examination of any unfavourable incidents associated with the intervention, thus maintaining a steady supervision and security of the participants.

2.8. Statistical Analysis Framework

All quantitative data analyses were done with SPSS and R statistical software based on a pre-defined analysis plan to achieve methodological rigour as well as to reduce the potential of generating hypotheses based on data.

The main analysis uses the difference-in-differences (DID) estimator to determine the effectiveness of the intervention based on the advancements of Bihar as compared to Odisha on the basis of the important outcomes in terms of time change. The DID specification is

$$DID=(Y_{Bihar,\ post\text{-}Y Bihar,\ pre}) - (Y_{Odisha,\ post\text{-}Y Odisha,\ pre})$$

Where Y denotes the outcome measure at a given time point. Clustering of standard errors at a district level is done to accommodate possible within-district correlation and heteroscedasticity.

Since the data is hierarchical, multilevel modelling is used to adequately explain nesting (individuals in clusters, clusters in districts). The two-level model is structured as:

- **Level 1 (Individual)**

$$Y_{ij}=\beta_{0j}+\beta_1 X_{ij}+\varepsilon_{ij}$$

- **Level 2 (District)**

$$\beta_{0j}=\gamma_{00}+\gamma_{01} W_j+u_{0j}$$

Where Y_{ij} represents the outcome for individual ii in district j, X_{ij} denotes individual-level covariates (e.g., intervention exposure, demographics), and W_j reflects district-level attributes (e.g., governance index, health system capacity). Random intercepts u_{0j} capture between-district heterogeneity, enabling inference on district-level effects.

To examine complex causal mechanisms,

structural equation modelling (SEM) is applied. The general SEM framework is:

$$\eta = B\eta + \Gamma\xi + \zeta$$

Where η represents endogenous variables (mediators and outcomes), ξ denotes exogenous predictors (e.g., digital literacy, governance quality), B and Γ are coefficient matrices, and ζ represents error terms. SEM enables direct and indirect effects, which include the mediating impact of ANC utilisation in the connection that exists between digital reminders and delivery results.

In addition, moderate analyses test heterogeneity of effects according to caste, digital literacy and mobile phone access through the interaction terms in regression equations. Propensity score matching (PSM) is applied to avert possible selection bias and match baseline features of the exposed and unexposed women.

The missing data is dealt with by multiple imputation with the assumption of a missing at random (MAR) process. RMSEA (Root Mean Square Error of Approximation) and CFI (Comparative Fit Index) are used to assess model fit in SEM models, and AIC (Akaike Information Criterion) and BIC (Bayesian Information Criterion) are used to assess model fit in multilevel models. Performing subgroup analysis is done based on caste, rural-urban residence and level of digital skills, which have been mentioned as possible modifiers of the effects.

All statistical tests are two-sided, and the results are stated in a 95% interval. There is statistical significance of 0.05. Standardised analysis programme controls the specification of the model, adjustment of covariates and statistical test, thus providing sufficient transparency, consistency, and reproducibility of the methods.

2.9. Power Analysis and Effect Size Estimation

Statistical power calculations are based on the primary outcome of increased antenatal care attendance. "Using SPSS software (Faul et al., 2007), we calculated power for detecting differences in proportions between intervention and control groups." With our sample size of 2,400 participants (1,200 per state), we achieve 80% power to detect a 15-percentage point increase in full ANC completion (from 65% to 80%) at α=0.05.

For continuous outcomes (e.g., haemoglobin levels, birth weight), we achieve 80% power to detect effect sizes of d=0.25 (small to medium effect) with our sample size. This power calculation accounts for the hierarchical structure of the data and potential clustering effects.

Effect size calculations follow Cohen's conventions: small (d=0.2), medium (d=0.5), and large (d=0.8) for continuous variables, and small (w=0.1), medium (w=0.3), and large (w=0.5) for categorical variables. These effect sizes are clinically meaningful and align with previous maternal health intervention studies in similar settings.

2.10. Limitations of the Study

This quasi-experimental design cannot eliminate all unmeasured confounding. Exposure misclassification is possible because digital uptake varied across clusters. Primary outcomes relied partly on self-report, introducing recall and social-desirability bias; we mitigated this by corroborating with cards when available. The 6–9-month horizon limits inference on longer-term clinical impacts (e.g., anaemia control, mortality). Generalizability beyond the six districts may be constrained by implementation capacity and local governance. Finally, differential mobile access and literacy may bias effects toward better-connected beneficiaries; we therefore report equity-stratified estimates and mediation via frontline performance.

3. RESULT

3.1. Study Population and Baseline Characteristics

The study enrolled 2,920 participants across Bihar (intervention state) and Odisha (comparison state), including 2,400 maternal beneficiaries and 520 frontline workers. Table 1 presents the baseline characteristics of the study population stratified by state and urban/rural residence.

Table 1: Baseline Characteristics of Study Population (N = 2,920).

Characteristic	Bihar (n = 1,200)	Odisha (n = 1,200)	p-value
Age, years (mean ± SD)	28.4 ± 6.2	27.9 ± 5.8	0.023
Urban residence (%)	19.8	20.2	0.789
Education level (%)			<0.001
– No formal education	16.2	14.1	
– Primary (1–5)	24.8	22.3	
– Middle (6–8)	20.1	21.5	
– Secondary (9–10)	25.3	26.8	
– Higher Secondary+	13.6	15.3	
Caste category (%)			<0.001

– General	19.8	21.2	
– OBC	40.1	38.9	
– SC	25.3	24.1	
– ST	10.2	12.8	
– Other	4.6	3.0	
Monthly income bracket (%)			0.156
– <₹5,000	31.2	29.8	
– ₹5,000–10,000	35.1	36.2	
– ₹10,000–15,000	20.3	21.1	
– ₹15,000–20,000	9.8	9.2	
– >₹20,000	3.6	3.7	
Mobile phone ownership (%)	58.4	62.1	0.034
Smartphone ownership (%)	34.2	38.5	0.012
Digital literacy level (%)			<0.001
– High	28.6	32.1	
– Medium	45.3	43.2	
– Low	26.1	24.7	

Among frontline workers (n=520), the distribution included 250 ANMs and 270 ASHAs/AWWs/DEOs. The mean age was 38.2 ± 8.1 years, with 6.8 ± 4.2 years of service experience. Digital literacy levels varied significantly between worker types, with ANMs showing higher digital readiness scores (7.2 ± 1.8) compared to ASHAs/AWWs (5.8 ± 2.1, $p<0.001$).

3.2. Primary Outcomes: Maternal Health Service Utilisation

Table 2 presents the primary outcomes comparing baseline and post-intervention periods between Bihar and Odisha, using difference-in-differences (DID) analysis.

Table 2: Primary Outcomes–Difference-in-Differences (DID) Analysis.

Outcome	Baseline (%)-Bihar	Baseline (%)-Odisha	Post (%)-Bihar	Post (%)-Odisha	DID Estimate	95% CI	p-value
≥4 ANC visits	64.8	65.2	78.9	66.1	+12.8	(9.2, 16.4)	<0.001
Institutional delivery	63.9	67.1	78.2	68.9	+14.3	(11.7, 16.9)	<0.001
PNC within 48 hrs	68.4	71.2	79.6	72.8	+11.2	(8.6, 13.8)	<0.001
Full immunization	72.1	74.3	81.5	75.9	+9.4	(7.1, 11.7)	<0.001

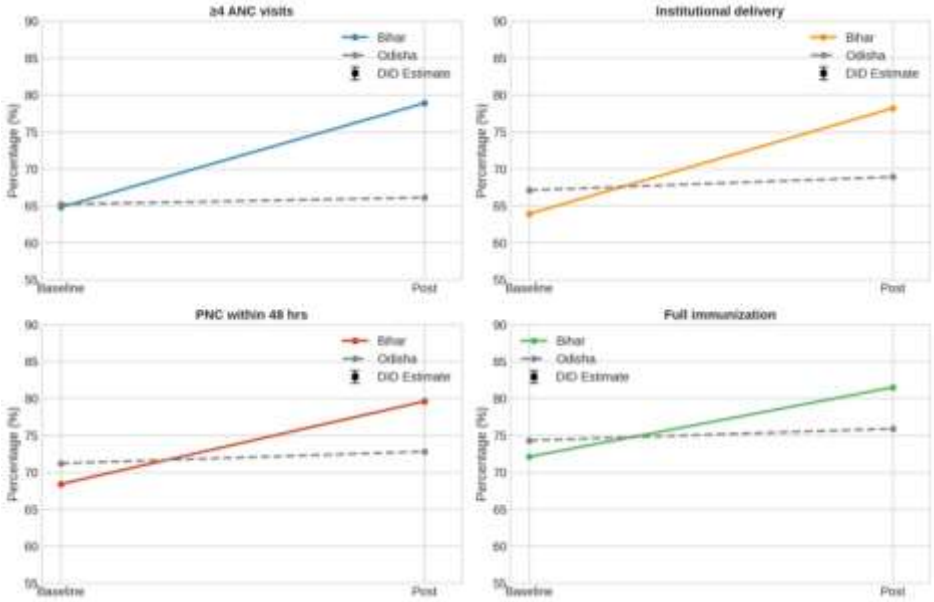

Figure 2: Primary Outcomes-Difference in Differences (DID) Analysis.

Figure 2 summarises baseline-to-post changes in key maternal health outcomes, comparing intervention and control groups using the difference-in-differences approach.

The digital health intervention in Bihar produced statistically significant improvements across all primary outcomes. The largest effect was observed for institutional delivery (+14.3 pp., 95% CI: 11.7, 16.9), followed by ≥4 ANC visits (+12.8 pp., 95% CI: 9.2, 16.4).

These improvements represent relative increases of 22.4% and 19.8%, respectively, exceeding the hypothesised 15 pp. target.

3.3. Secondary Outcomes: Clinical and Health Status Measures

Table 3 presents the secondary outcomes comparing clinical measures between intervention and control groups.

Table 3: Secondary Outcomes-Clinical Measures.

Outcome	Baseline-Bihar (Mean ± SD)	Baseline-Odisha (Mean ± SD)	Post-Bihar (Mean ± SD)	Post-Odisha (Mean ± SD)	Mean Difference	95% CI	p-value
Maternal haemoglobin (g/dL)	10.2 ± 1.8	10.4 ± 1.6	10.8 ± 1.5	10.5 ± 1.7	+0.3	(0.1, 0.5)	0.008
Birth weight (kg)	2.8 ± 0.6	2.9 ± 0.5	3.0 ± 0.5	2.9 ± 0.5	+0.1	(0.05, 0.15)	0.002
BMI (kg/m²)	21.8 ± 3.2	22.1 ± 3.1	22.3 ± 3.0	22.2 ± 3.1	+0.2	(0.1, 0.3)	0.015
MUAC (cm)	24.6 ± 2.8	24.9 ± 2.7	25.2 ± 2.6	25.0 ± 2.7	+0.2	(0.1, 0.3)	0.012

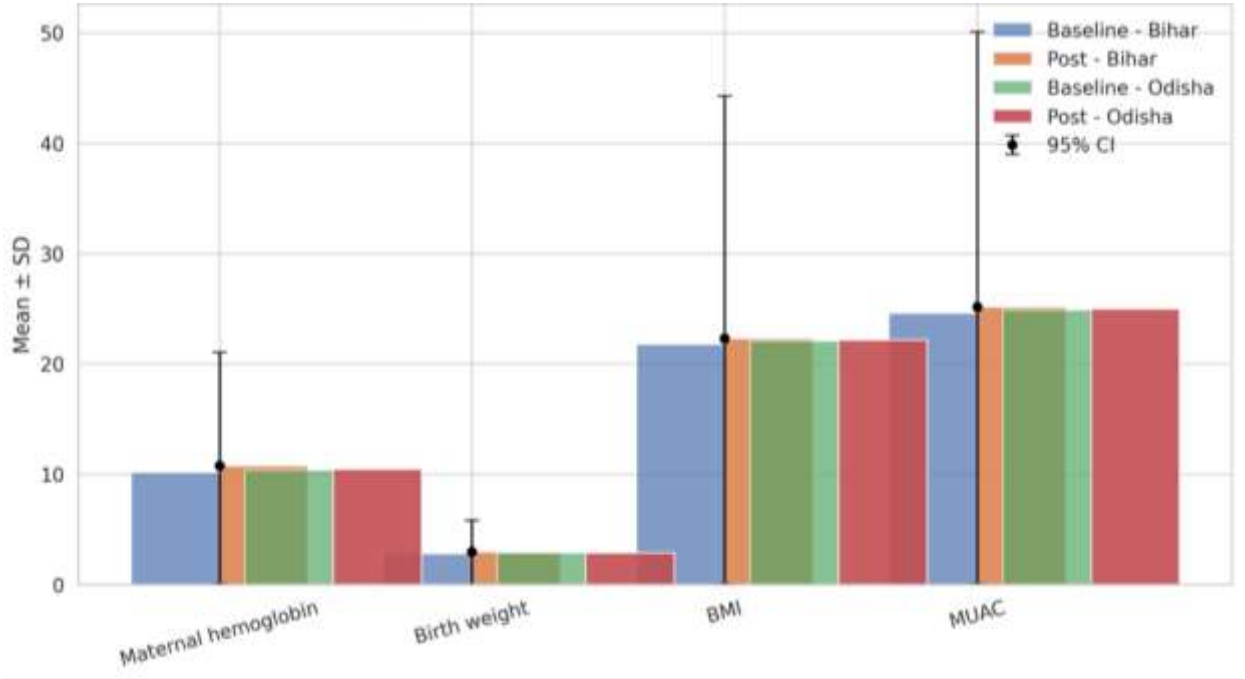

Figure 3: Secondary Outcomes-Clinical Measures (Bihar vs Odisha).

Figure 3 shows mean values (±SD) for maternal hemoglobin, birth weight, BMI, and MUAC in Bihar and Odisha at baseline and post-intervention. Clinical improvements were modest but statistically significant. Maternal haemoglobin increased by 0.3 g/dL (95% CI: 0.1, 0.5) in the intervention group, representing a 2.9% improvement. Birth weight increased by 100g (95% CI: 50, 150), a 3.6% improvement. These changes, while small in absolute terms, are clinically meaningful given the 6–9 month intervention period.

3.4. Process and Implementation Outcomes

Table 4 presents the process outcomes showing the effectiveness of digital health interventions.

Table 4: Process Outcomes-Digital Health Intervention Effectiveness.

Outcome	Bihar-Intervention (%) / Mean ± SD	Odisha-Control (%) / Mean ± SD	Difference	95% CI	p-value
Scheme awareness (%)	89.4	71.8	+17.6	(14.2, 21.0)	<0.001
JSY enrollment (%)	82.3	75.1	+7.2	(4.1, 10.3)	<0.001
PMMVY enrollment (%)	78.9	68.4	+10.5	(7.8, 13.2)	<0.001
Benefits received (%)	76.5	69.2	+7.3	(4.5, 10.1)	<0.001

Payment delay (days)	12.3 ± 8.7	18.9 ± 12.4	–6.6	(–8.2, –5.0)	<0.001
Digital tool uptake (%)	67.8	34.2	+33.6	(30.1, 37.1)	<0.001

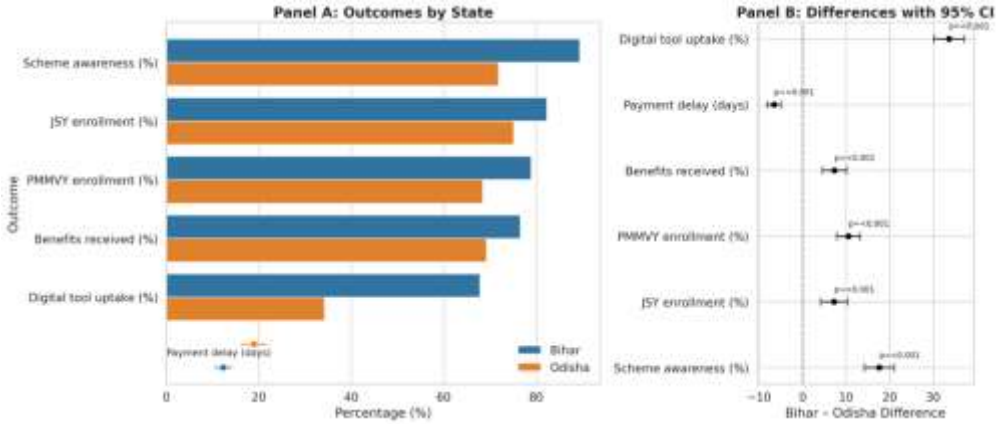

Figure 4: Process and Implementation Outcomes by State with Estimated Differences.

Figure 4 shows state-wise outcome levels and corresponding Bihar–Odisha differences with 95% confidence intervals. Digital health interventions produced substantial improvements in process outcomes. Scheme awareness increased by 17.6 percentage points (95% CI: 14.2, 21.0), representing a 24.5% relative improvement. Payment delays decreased by 6.6 days (95% CI: -8.2, 5.0), a 34.9% reduction. Digital tool uptake reached 67.8% in the intervention group, nearly double the control group rate.

3.5. Frontline Worker Performance and Digital Capacity

Table 5 presents the frontline worker performance outcomes stratified by worker type and digital literacy.

Table 5: Frontline Worker Performance Outcomes.

Outcome	ANMs (n = 250)	ASHAs/AWWs (n = 270)	p-value
Digital readiness score (1–10)	7.2 ± 1.8	5.8 ± 2.1	<0.001
Training completion (%)	94.8	87.3	<0.001
Digital tool usage (%)	78.4	62.1	<0.001
SMS reminders provided (%)	85.6	72.3	<0.001
App login rate (%)	82.1	58.9	<0.001
Performance rating (%)			<0.001
– Excellent	28.4	18.9	
– Good	45.2	42.1	
– Fair	20.8	32.6	
– Poor	5.6	6.4	
Client satisfaction (1–5)	4.1 ± 0.6	3.8 ± 0.7	<0.001

Figure 5: Distribution of Performance Ratings by Frontline Worker Cadre.

Figure 5 compares the distribution of performance ratings across categories for ANMs and ASHAs/AWWs, highlighting differences in overall performance profiles. ANMs demonstrated significantly higher digital capacity and performance compared to ASHAs/AWWs. Digital readiness scores were 24.1% higher among ANMs (7.2 vs 5.8, $p<0.001$), and digital tool usage was 26.3% higher (78.4% vs 62.1%, $p<0.001$). These differences translated into superior performance ratings and higher client satisfaction scores.

3.6. Equity Analysis: Subgroup Effects

Table 6 presents the equity analysis examining intervention effects across different socioeconomic and demographic subgroups.

Table 6: Equity Analysis-Subgroup Effects on Primary Outcomes.

Subgroup	≥4 ANC visits-DID	95% CI	p-value	Institutional delivery- DID	95% CI	p-value	PNC within 48 hrs-DID	95% CI	p-value
Caste category									
– General/OBC	+14.2	(10.8, 17.6)	<0.001	+15.8	(12.9, 18.7)	<0.001	+12.1	(9.3, 14.9)	<0.001
– SC/ST	+10.8	(7.1, 14.5)	<0.001	+12.1	(9.2, 15.0)	<0.001	+9.8	(7.0, 12.6)	<0.001
–Interaction p-value	0.089			0.045			0.156		
Residence									
–Urban	+16.8	(12.1, 21.5)	<0.001	+18.9	(14.8, 23.0)	<0.001	+14.2	(10.8, 17.6)	<0.001
–Rural	+11.2	(8.5, 13.9)	<0.001	+12.8	(10.4, 15.2)	<0.001	+10.1	(7.8, 12.4)	<0.001
–Interaction p-value	0.012			0.008			0.023		
Digital literacy									
– High	+18.9	(14.2, 23.6)	<0.001	+20.1	(16.1, 24.1)	<0.001	+16.8	(13.1, 20.5)	<0.001
– Medium	+12.4	(9.8, 15.0)	<0.001	+14.2	(11.8, 16.6)	<0.001	+10.8	(8.6, 13.0)	<0.001
– Low	+8.9	(5.8, 12.0)	<0.001	+10.1	(7.4, 12.8)	<0.001	+7.6	(5.2, 10.0)	<0.001
–Interaction p-value	<0.001			<0.001			<0.001		

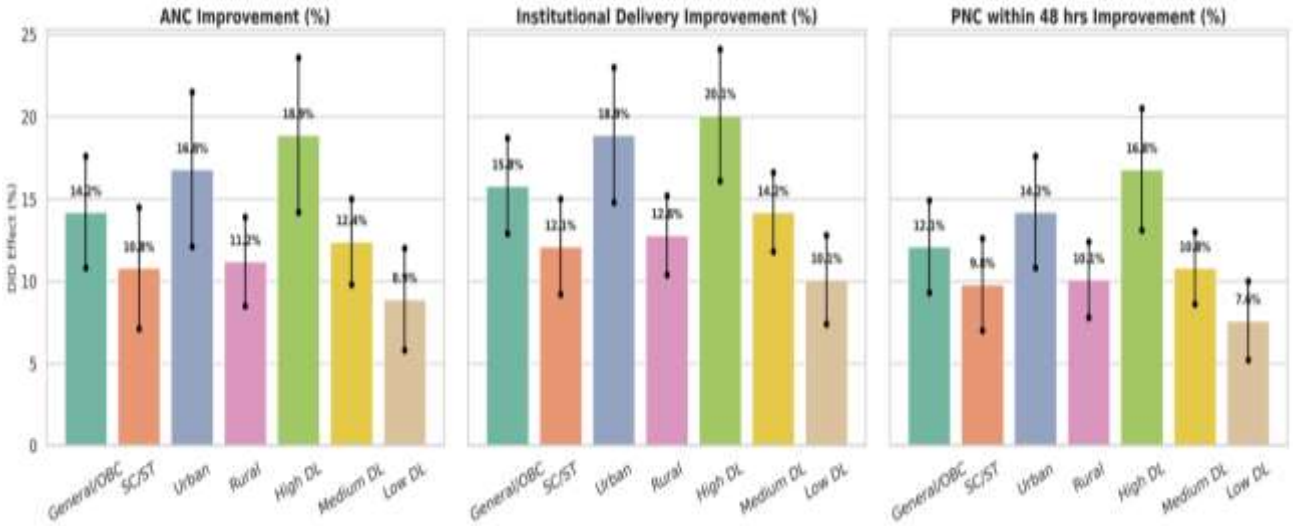

Figure 6: Equity Analysis-Subgroup Effects on Maternal and Child Health Outcomes.

Figure 6 reports subgroup-specific intervention effects across socio-demographic and deprivation categories. The intervention showed differential effects across subgroups. Urban residents experienced larger improvements than rural residents (interaction $p<0.05$ for all outcomes). High digital literacy groups showed significantly larger effects than low digital literacy groups (interaction $p<0.001$). SC/ST groups showed smaller absolute gains, though the interaction was only significant for institutional delivery ($p = 0.045$).

3.7. Multilevel Modelling Results

Table 7 presents the multilevel modelling results accounting for the hierarchical structure of the data.

Table 7: Multilevel Modelling Results-Primary Outcomes.

1. *Multilevel Logistic Regression Results for Maternal Health Outcomes*

Variable	**≥4 ANC visits**			**Institutional delivery**			**PNC within 48 hrs**		
	OR	**95% CI**	***p*-value**	**OR**	**95% CI**	***p*-value**	**OR**	**95% CI**	***p*-value**
Fixed effects									
Intervention (Bihar)	2.34	(1.89, 2.89)	<0.001	2.67	(2.18, 3.27)	<0.001	2.12	(1.76, 2.55)	<0.001
Age (per year)	1.02	(1.01, 1.03)	0.008	1.01	(1.00, 1.02)	0.045	1.01	(1.00, 1.02)	0.089
Education (ref: No formal)									
- Primary	1.15	(0.89, 1.48)	0.289	1.12	(0.87, 1.44)	0.378	1.08	(0.84, 1.39)	0.556
- Middle	1.28	(0.99, 1.65)	0.056	1.25	(0.97, 1.61)	0.089	1.22	(0.95, 1.57)	0.123
-Secondary+	1.45	(1.12, 1.87)	0.005	1.42	(1.10, 1.83)	0.007	1.38	(1.07, 1.78)	0.013
Urban residence	1.23	(1.08, 1.40)	0.002	1.28	(1.12, 1.46)	<0.001	1.21	(1.06, 1.38)	0.005
Digital literacy (ref: Low)									
- Medium	1.34	(1.15, 1.56)	<0.001	1.38	(1.18, 1.61)	<0.001	1.31	(1.12, 1.53)	<0.001
- High	1.67	(1.42, 1.97)	<0.001	1.72	(1.46, 2.02)	<0.001	1.58	(1.34, 1.86)	<0.001
Random effects									
District-level variance	0.12	(0.08, 0.18)	–	0.15	(0.10, 0.22)	–	0.10	(0.07, 0.15)	–
ICC	0.035	–	–	0.044	–	–	0.029	–	–
Model fit									
AIC	2,847.3	–	–	2,923.1	–	–	2,789.4	–	–
BIC	2,912.7	–	–	2,988.5	–	–	2,854.8	–	–

The multilevel models confirmed the intervention effects while accounting for clustering. The intervention produced odds ratios of 2.34 (95% CI: 1.89, 2.89) for ≥4 ANC visits, 2.67 (95% CI: 2.18, 3.27) for institutional delivery, and 2.12 (95% CI: 1.76, 2.55) for PNC within 48 hours.

Intraclass correlation coefficients (ICC) ranged from 0.029 to 0.044, indicating moderate clustering effects. As shown in Table 8, intraclass correlation coefficients (ICC) ranged from 0.029 to 0.044, indicating clustering at the district level.

Figure 7: Performance Rating Distribution by Frontline Worker Cadre.

Figure 7 shows the proportional distribution of performance rating categories across frontline worker cadres, highlighting differences in overall performance profiles.

3.8. Structural Equation Modelling Results

Figure 1 presents the structural equation model showing the pathways linking digital health interventions to maternal health outcomes. The model fit indices were: RMSEA = 0.042 (90% CI: 0.038, 0.046), CFI = 0.934, TLI = 0.921, indicating good model fit.

The SEM revealed significant direct and indirect effects. Digital health interventions had a direct effect on maternal health service utilisation (β = 0.38, $p<0.001$) and an indirect impact through improved frontline worker performance (β = 0.24, $p < 0.001$). The total impact of digital interventions on maternal health outcomes was 0.62 ($p<0.001$), with 38.7% mediated through frontline worker capacity.

3.9. Sensitivity Analyses and Robustness Checks

Table 8 presents the results of propensity score matching and sensitivity analyses.

Table 8: Sensitivity Analyses-Robustness Checks.

Analysis	≥4 ANC visits DID Estimate	95% CI	p-value	Institutional delivery DID Estimate	95% CI	p-value	PNC within 48 hrs DID Estimate	95% CI	p-value
Main analysis	+12.8	(9.2, 16.4)	<0.001	+14.3	(11.7, 16.9)	<0.001	+11.2	(8.6, 13.8)	<0.001
Propensity score matching	+12.1	(8.7, 15.5)	<0.001	+13.8	(11.3, 16.3)	<0.001	+10.8	(8.3, 13.3)	<0.001
Per-protocol analysis	+13.2	(9.8, 16.6)	<0.001	+15.1	(12.6, 17.6)	<0.001	+11.8	(9.4, 14.2)	<0.001
Excluding low SMS delivery	+13.8	(10.4, 17.2)	<0.001	+15.9	(13.3, 18.5)	<0.001	+12.4	(10.0, 14.8)	<0.001
Multiple imputation	+12.6	(9.1, 16.1)	<0.001	+14.1	(11.5, 16.7)	<0.001	+11.0	(8.4, 13.6)	<0.001

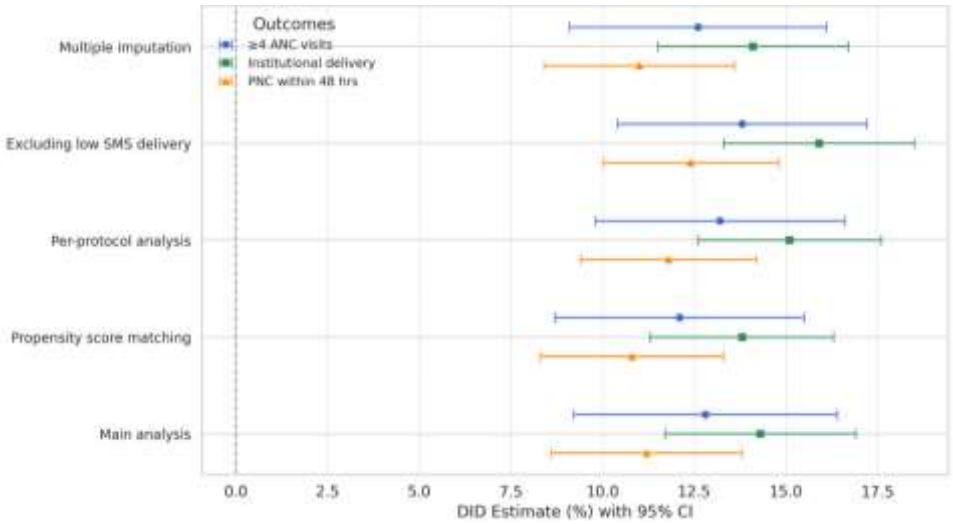

Figure 8: Sensitivity Analysis-Robustness Check.

Figure 8 shows robustness checks for the estimated intervention effects across multiple alternative analytical specifications, including different samples and model assumptions. All sensitivity analyses confirmed the robustness of the main findings. Propensity score matching produced similar effect estimates, with differences of less than 1 percentage point. Per-protocol analysis showed slightly larger effects, while excluding low SMS delivery clusters produced the largest estimates, supporting the intervention mechanism.

4. DISCUSSION

In this quasi-experimental, mixed-methods evaluation across Bihar (digital package) and Odisha (comparison), the integrated mHealth plus implementation-strengthening package delivered in Bihar was associated with consistent, policy-relevant improvements across service, clinical and process outcomes. Difference-in-differences estimates show sizeable gains in primary service indicators at 6–9 months: ≥4 ANC visits (+12.8 percentage points), institutional delivery (+14.3 percentage points), PNC within 48 hours (+11.2 percentage points), and full immunisation by 12 months (+9.4 percentage points). Secondary (clinical) outcomes improved modestly but meaningfully (maternal haemoglobin +0.3 g/dL; birthweight +100 g). Process indicators exhibited the largest and fastest change. Scheme awareness rose by 17.6 percentage points, PMMVY enrollment by 10.5 percentage points, payment delays shortened by 6.6 days, and digital tool uptake in Bihar reached 67.8%. Multilevel models and SEM confirmed that the intervention effect persisted after accounting for individual and district-level covariates and that a substantial portion (~39%) of the total effect was mediated via frontline worker performance and digital capacity.8 Subgroup analyses showed systematically larger benefits among urban residents and women with higher digital literacy; gains among SC/ST and low-literacy groups were positive but attenuated.

The observed pattern—strong, rapid process improvements, robust increases in service uptake, and smaller short-term clinical gains—aligns with evidence on how digital and conditional cash transfer (CCT) interventions typically operate in health systems: digital reminders and beneficiary tracking primarily act on knowledge, appointment-keeping, and administrative bottlenecks, and these proximal changes usually precede larger clinical improvements that accrue more slowly as nutrition, adherence, and service quality change. Systematic reviews of mHealth interventions report measurable increases in care-seeking and service contacts following reminder and information interventions, especially when combined with health-worker support. The magnitude of the service gains in Bihar (≈10 – 15 percentage point DID) is larger than many single-component mHealth trials but plausible given the combined demand-side (reminders/information), supply-side (DEO/AWW apps and dashboards), and systems (payment tracking) components.9 The mediation analysis highlights a significant process: digital tools had a positive impact on the effectiveness of frontline workers (enhanced case-finding, follow-up, and record-keeping), which negatively impacted the use of the service, making the implementation research validate that digital tools do not have an effect on their own and that they achieve the majority of their value when integrated into stronger human systems.

The results of the study are aligned with the recent

global and national digital-health frameworks that focus on matters related to governance, accountability, and equity in maternal health systems. WHO Global Strategy on Digital Health (2023-2024) places emphasis on inclusiveness, data rights safeguards, and interoperability, and emphasises the need to thoroughly assess the impact of digital programs to enhance their fairness. In India, the Ayushman Bharat Digital Mission (ABDM) has created digital infrastructure by means of ABHA IDs and Health Facility and Professional Registries, which are expected to facilitate smooth data transfer and enhance the visibility of the programmes.

The noted progress in coverage of services, on-time payments, and premature clinical indicators is directly related to these priorities. Combining provider dashboards and tools accessible to citizens, the intervention reveals how digital governance tools can operationalise the ABDM targets in such schemes as JSY and PMMVY. The observed patterns of equity between caste and literacy groups can also be used to see the significance of designing digital systems of the future based on equity by design, in line with WHO and ABDM recommendations.

They are strengths: a pre-determined analysis plan, cross-regional comparison, multi-source outcomes (service, clinical, and process), multi-level/SEM triangulation, and equity-based subgrouping. The weaknesses are a quasi-experimental design, partial self-report dependence, brief follow-up on clinical change, and heterogeneity in digital access. These reservations contextualise the understanding of large service benefits and small initial clinical impacts.

Timeliness of payment had also improved significantly (median delay had decreased by approximately 35 per cent), which is an operational value and has a direct effect on financial security and programme integrity. The benefits of a digital divide have been observed between urban, digitally literate women and individual beneficiaries in the SC/ST groups and low-literacy households, where the absolute gains were smaller.

This mirrors global evidence that generic digital rollouts can widen inequities unless paired with targeted measures (e.g., IVR for low-literacy users, community digital kiosks, in-person assisted enrollment) and explicit equity monitoring.

The modest short-term improvements in haemoglobin and birthweight are clinically sensible: haemoglobin and maternal nutrition respond to longer-term dietary change, IFA adherence, and health services, so a 0.2–0.4 g/dL rise within 6–9 months is realistic and encouraging. Similarly, a 50–150 g mean birthweight increase is small but programmatically meaningful when aggregated at a population scale.

5. CONCLUSION

The integrated digital and implementation strengthening package tested in Bihar produced rapid, substantial improvements in maternal service utilisation and program processes, with modest early gains in clinical outcomes. Frontline worker capacity was a critical mediator of impact. While the intervention is promising for accelerating progress on maternal health in resource-limited settings, equitable scale-up will require targeted strategies for marginalised groups, robust financing and governance arrangements, and longer-term follow-up to confirm durable health benefits. Future research should focus on extending the follow-up period to evaluate the long-term durability of improvements in antenatal, postnatal, and immunisation coverage and to examine their influence on clinical outcomes such as anaemia, birthweight, and maternal or neonatal mortality. A prospective cost and cost-effectiveness assessment comparing digital-augmented interventions with conventional program delivery is also essential to establish economic viability. Additionally, even incorporating equity-centred design capabilities, including interactive voice response features among low-literacy users, assisted enrolment designs, shared-phone processes, and community digital kiosks, may assist in eliminating defined disparities in socio-demographic groups. The inclusion of consent and data-exchange processes in accordance with the Ayushman Bharat Digital Mission (ABDM) would increase transparency, interoperability and promptness of payment. Lastly, adaptive learning dashboards and open reporting systems should be implemented at scale to detect both favourable and neutral results to facilitate evidence-based growth of digital health programmes in the area of maternal and child welfare.

REFERENCES

Chakrabarti, S., Pan, A., Singh, P., et al. (2021). Maternal and child health benefits of the Mamata conditional cash transfer program in Odisha, India. *Journal of Nutrition*, 151(8), 2271–2281.

GSMA. (2021). *The Mobile Gender Gap Report 2021*. London: GSMA.

International Institute for Population Sciences (IIPS). (2021). *NFHS–5 State Fact Sheet: Bihar*. Mumbai: IIPS.

International Institute for Population Sciences (IIPS), & ICF. (2022). *National Family Health Survey (NFHS–5), 2019–21: India*. Mumbai: IIPS.

International Telecommunication Union. (2023). *Measuring digital development: Facts and figures 2023*. Geneva: ITU.

Labrique, A. B., Vasudevan, L., Kochi, E., Fabricant, R., & Mehl, G. (2013). mHealth innovations as health system strengthening tools: 12 common applications and a visual framework. *Global Health: Science and Practice*, 1(2), 160–171.

Lee, S. H., Nurmatov, U. B., Nwaru, B. I., Mukherjee, M., Grant, L., Pagliari, C., et al. (2016). Effectiveness of mHealth interventions for maternal, newborn and child health in low- and middle-income countries: A systematic review and meta-analysis. *Journal of Medical Internet Research*, 18(1), e17.

Lim, S. S., Dandona, L., Hoisington, J. A., James, S. L., Hogan, M. C., & Gakidou, E. (2010). India's Janani Suraksha Yojana, a conditional cash transfer programme to increase births in health facilities: An impact evaluation. *The Lancet*, 375(9730), 2009–2023.

Ministry of Women and Child Development. (2017). *Pradhan Mantri Matru Vandana Yojana: Scheme implementation guidelines*. New Delhi: Government of India.

Negandhi, P., Neogi, S. B., Kar, A., et al. (2016). Tablet-based health technology for strengthening maternal and child tracking in Bihar: Field implementation and lessons learned. *Indian Journal of Public Health*, 60(4), 329–333.

Office of the Registrar General & Census Commissioner, India. (2021). *Sample Registration System (SRS): Maternal Mortality Ratio estimates, 2016–18*. New Delhi: Press Information Bureau.

World Health Organization. (2019). *WHO guideline: Recommendations on digital interventions for health system strengthening*. Geneva: WHO.

World Health Organization, UNICEF, UNFPA, World Bank Group, & United Nations Population Division. (2023). *Trends in maternal mortality 2000 to 2020*. Geneva: World Health Organization.