A Multi-Dimensional Assessment of Maternal-Child Health, Quality of Care, and Digital Innovations

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ABSTRACT

Background: Bihar has been one of the poorest states in India in terms of maternal and neonatal mortality. Furthermore, low maternal and child health indicators (MCH) exposed the state's health system's vulnerabilities, which affect the overall health function and position the state low in national and global health rankings. Although frontline workers (FLWs), who are community representatives, are the direct point of contact for reaching the right beneficiaries, they often lack the necessary skills and capacities to deliver services on time. Apart from this, the state often witnessed operational challenges that prevented the smooth functioning of service provisions scheduled for beneficiaries. Women have been the most disadvantaged section when it comes to accessing various social welfare schemes meant for them. Due to socio-cultural norms, caste, educational status, and geographical differentiation, women's access to maternal benefit schemes is significantly influenced. These inequalities are not only social but also spatial, reflecting uneven regional development and the need for geographically inclusive social planning. Notably, the Janani Suraksha Yojana (JSY) and the Pradhan Mantri Matru Vandana Yojana (PMMVY) are the two major maternity benefit schemes operating in the state of Bihar to use conditional cash transfers (CCT) not only to improve MCH outcomes but also to promote equitable regional development through better social planning.

Methods: This study assesses the effectiveness of JSY and PMMVY in Bihar. We used a cross-sectional survey of 390 frontline workers, supplemented by facility audits and beneficiary assessments, to examine program coverage, service quality, digital readiness, and psychosocial dimensions of implementation. A spatially comparative design was adopted across rural and semi-urban districts to capture geographic disparities in implementation and digital outreach. One rural district and one semi-urban district were chosen for the study, and within each district, five blocks were randomly selected. Stratified random sampling was employed to select study participants, and informed consent was obtained prior to collecting any data and information. All instruments were pre-tested with $n = 10$ frontline workers. Fieldwork took place from January 2024 to November 2024. Descriptive and multivariable statistical analyses were applied to examine regional and social variations in implementation. All analyses were performed using *SPSS* and *R*, with a statistical significance level of $\alpha = 0.05$, and effect sizes reported with 95% confidence intervals.

Results: Receipt of PMMVY and JSY was considered with significantly higher utilization of recommended maternal services, including four or more antenatal care visits ,institutional deliveries and early postnatal care in selected districts of Bihar (Table 2). From a CCT perspective, facilities rated as high-quality saw 7–11% higher program implementation rates (Table 3). FLWs reporting higher job satisfaction and support networks also had stronger program performance (Table 4). FLWs with higher digital engagement and literacy achieved substantially higher JSY/PMMVY awareness and timely enrolment (Table 5). Marked rural–urban and district-level variations indicate that spatial and infrastructural factors shape welfare delivery, while digital literacy serves as a bridging tool reducing geographic inequities.

Conclusion: Findings highlight substantial uptake of JSY/PMMVY but reveal variation by geography, caste, and facility quality. Digital literacy and outreach significantly enhance awareness and timeliness of benefit delivery, while frontline workers' job satisfaction and stress levels influence implementation effectiveness. Cash transfers alone are insufficient: complementary investments in service quality, equity-focused outreach, and digital systems are essential to maximise health impact in Bihar. These findings highlight the importance of spatially sensitive social planning and digital innovation in achieving equitable maternal welfare and balanced regional development.

INTRODUCTION

Bihar's maternal and child health indicators continue to lag behind national averages, exposing deep socio-economic and health-system vulnerabilities that disproportionately affect marginalised groups. These disparities also mirror long-standing spatial and developmental imbalances across districts, where access to services, infrastructure, and governance capacity vary widely. Infant and neonatal mortality, undernutrition, and low coverage of recommended antenatal care remain pressing concerns in the state (International Institute for Population Sciences 2021). Such conditions underscore how uneven regional development and limited spatial planning perpetuate maternal and child health disadvantages across Bihar. In recent years, digital innovation has emerged as a potential tool to address these gaps, enabling spatially inclusive health communication, data tracking, and service coordination across geographically uneven regions. Aggregate statistics obscure pronounced spatial and social inequities: women from lower castes, with little formal education, or living in remote rural areas are consistently less likely to access antenatal, intrapartum, and postnatal services (Sanneving et al. 2013). The persistence of such gaps, despite major national programs, points to a core policy puzzle: why do demand-side financial incentives, designed to increase service use, produce uneven spatial and developmental outcomes in places such as Bihar?

India's two prominent maternity support programs, Janani Suraksha Yojana (JSY), launched in 2005, and Pradhan Mantri Matru Vandana Yojana (PMMVY), rolled out more recently, represent large-scale social protection interventions employing conditional cash transfers (CCTs) to advance maternal welfare and promote regional development equity. JSY provided cash incentives for institutional delivery under the National Rural Health Mission (NRHM), with special emphasis on "*low*-performing" states, including Bihar (Government of India, Ministry of Health and Family Welfare 2005). By prioritising such states, the program also functioned as a regional development mechanism aimed at reducing inter-state disparities in maternal well-being. PMMVY subsequently introduced targeted cash assistance for pregnant and lactating mothers, altering the benefit structure and administrative arrangements (Ministry of Women and Child Development 2017). Together, JSY and PMMVY link social policy with spatial planning, positioning maternal welfare within India's broader human development and decentralised governance agenda.

Evaluations across India have most often documented increases in selected service-use indicators (institutional delivery, some antenatal contacts), but evidence on downstream child-health outcomes and on heterogeneous impacts across social groups is mixed (Glassman et al. 2013; Hunter and Murray 2017). However, limited attention has been paid to how geographic and infrastructural disparities shape these program impacts, particularly in low-resource regions. In Bihar specifically, recent administrative data reveal considerable district-level variation in PMMVY enrollment and timely disbursement, highlighting implementation gaps that may undermine expected health effects (Government of India, Ministry of Women and Child Development 2025). These patterns reflect spatially uneven administrative performance and differences in local developmental capacity across districts. Digital platforms, if integrated into welfare governance, can help overcome some of these administrative and spatial barriers by improving transparency, monitoring, and outreach to remote beneficiaries.

This study situates the Bihar experience within two complementary theoretical frames. The analysis also draws from developmental geography, linking conditional cash transfers to broader questions of spatial justice and equitable regional planning. Firstly, Conditional Cash Transfer (CCT) theory treats cash incentives as an economic instrument that reduces liquidity constraints and raises demand for health services, thereby functioning as a targeted human-capital investment (Glassman et al. 2013). From this perspective, JSY/PMMVY should increase attendance at antenatal clinics, institutional births, and basic preventive childcare. Secondly, the Social Determinants of Health framework emphasises how structural factors like caste, gender norms, education, poverty, and geography and spatial accessibility mediate the translation of incentives into health

outcomes (Sanneving et al. 2013; Creswel & Clark, 2017). A distinguishing feature of the present study is that it integrates these perspectives, treating cash incentives as necessary but not sufficient, and explicitly examines the social and service-system conditions that enable or constrain program effectiveness. By doing so, it interprets welfare programs as instruments of spatial development, illustrating how place, infrastructure, and governance interact with individual-level incentives. Within this framework, digital innovation is treated as both a governance and planning instrument that connects policy implementation with spatial equity goals.

Three key empirical and conceptual gaps motivate our inquiry. These also reflect gaps in understanding how spatial and infrastructural factors condition policy success and regional inclusivity. Firstly, most prior evaluations emphasise uptake metrics (e.g., awareness, number of institutional deliveries) but seldom investigate the geographic and service-quality dimensions of care as mediators: whether women who are incentivised to use facilities experience respectful, timely, and clinically adequate care (Mahapatro & Sethy, 2025). Secondly, the psychosocial dimension of maternity care, particularly maternal mental health-has been largely absent from quantitative assessments of JSY/PMMVY in Bihar, even though cash transfers may reduce financial stress and thereby influence postpartum depression and caregiving capacity (Powell-Jackson et al. 2016). Third, the potential of digital innovation including digital outreach and IT-enabled delivery systems for beneficiary identification, information dissemination, and grievance redressal to increase awareness and reduce leakage remains under-explored in the Bihar context, despite promising findings for mHealth interventions in comparable Indian states (Singh and Walters 2024; Mehta et al., 2023). Digital platforms also have spatial implications, helping bridge rural–urban divides and enabling geographically inclusive access to welfare information. Digital innovations therefore operate not merely as communication tools but as development infrastructure that supports participatory planning and reduces geographic exclusion. Taken together, these gaps suggest that focusing solely on cash disbursement and service counts may yield an incomplete picture of program performance.

To address these lacunae, this paper asks the following research questions:

1) Does receipt of JSY or PMMVY increased use of recommended maternal services such as four or more antenatal care visits, institutional delivery, and early postnatal care in selected districts of Bihar?

2) Do facility quality factors, including client experience, waiting time, and provider behaviour, modify the effect of JSY or PMMVY on maternal and newborn outcomes?

3) Is receipt of JSY or PMMVY associated with improved maternal mental health, and does improved maternal mental health mediate better child health inputs such as immunisation and early nutrition?

4) Does exposure to digital outreach through SMS or Accredited Social Health Activists (ASHA) apps increase awareness, timely enrolment, and receipt of JSY or PMMVY benefits?

Collectively, these questions aim to uncover how social, geographic, and institutional contexts interact to shape the developmental effectiveness of maternal welfare programs in Bihar. From these questions, we derive testable hypotheses. Firstly, consistent with CCT theory, we hypothesise that beneficiaries will exhibit higher utilisation of recommended maternal services than comparable non-beneficiaries. We further expect this effect to vary spatially, reflecting differences in infrastructure, connectivity, and governance across districts. Second, we hypothesise that service quality will significantly moderate this relationship: the positive effect of cash on health outcomes will be attenuated where perceived facility quality is poor. Third, we hypothesise that beneficiaries will report lower levels of postpartum distress, mediating some of the observed child-care advantages. Fourth, we hypothesise that digital outreach exposure will be positively associated with awareness, enrolment, and timeliness of benefits, thereby strengthening program impact.

This study will offer a comprehensive answer to whether and how maternity benefits "work" in Bihar. It approaches this question not only as a matter of public health, but as an inquiry into regional social development and spatial equity. By adding digital, mental health, and quality dimensions to the analysis, we address gaps highlighted in the literature. Policymakers have called for evidence on implementation bottlenecks and unintended effects of JSY/PMMVY-for instance, whether poor service quality or lack of outreach undermines program gains. Addressing these issues through a spatial and social planning lens offers insights relevant to other low-development regions. Emphasizing digital innovation as part of this planning lens allows for scalable and sustainable strategies that integrate technology with governance and spatial inclusion. Our findings will inform whether complementary investments (e.g., improving facility quality or scaling digital health) are needed alongside cash transfers. Theoretically, we will deepen our understanding of CCTs by embedding them in a health equity framework. In sum, this interdisciplinary, policy-

relevant study promises both practical guidance for Bihar's maternal health programs and broader insights into how demand-side incentives interact with social, spatial, and governance factors in resource-poor settings.

LITERATURE REVIEW

This review integrates evidence from academic research and official sources on maternity cash incentives, maternal-child health, and related interventions in India, with a focus on Bihar. It particularly emphasises the spatial and social development dimensions of maternal welfare, situating cash transfer programs within the broader geography of health equity and regional planning. We grounded the study in Conditional Cash Transfer (CCT) theory and social determinants frameworks, extending these to a developmental geography perspective that considers how place, infrastructure, and governance shape program outcomes. In CCT models, cash incentives are viewed as investments in human capital: by reducing financial barriers, they encourage health-seeking behaviour (for example, by requiring antenatal visits or facility delivery). Reviews find CCTs generally boost service utilisation (ANC visits, skilled birth attendance, immunisations) and can improve some health inputs and outcomes. However, from a planning and development perspective, the extent of these improvements often depends on how well welfare schemes are spatially targeted and integrated into regional social infrastructure (Banerjee et al., 2025). Recent discussions in social policy and development geography also highlight the role of digital innovation in strengthening this integration, allowing governments to spatially map beneficiaries, monitor delivery in real time, and enhance inclusion through technology-driven outreach.

For instance, Glassman et al. (2013) report that maternity CCT programs raised antenatal care attendance, institutional delivery, and tetanus vaccination, and even reduced low birthweight incidence, although longer-term impacts on mortality are less documented. However, the effectiveness of CCTs depends on program design and context. Bhattacharyya et al. (2025), in a recent scoping review of maternity benefits, emphasise that elements like benefit size, payment timing, and enforcement of conditions (e.g. mandatory ANC checks) critically shape outcomes. They note challenges such as poor awareness of entitlements, limited women's agency over cash use, and health-system constraints (e.g. staffing, supply shortages) that can undermine impact. Hunter and Murray (2017) similarly stress that demand-side incentives must be accompanied by supply-side improvements; their review of demand-side financing in maternal health found that cash or voucher schemes often increase service uptake only where infrastructure, staffing and quality of care are adequate. As they conclude, "financial and other social, geographical and health systems factors" remain barriers even with cash incentives, and programs must address issues like facility quality and outreach to marginalised groups. In contemporary welfare contexts, such outreach increasingly depends on digital systems mobile platforms, online grievance tools, and data dashboards that expand participation and reduce spatial barriers. This aligns with a spatial equity lens, where access to health benefits is shaped by both physical geography and social stratification.

ssPublic Health Context and Equity in Bihar

Bihar's maternal-child health indicators lag behind national averages, reflecting deep social and geographic inequities. Social determinants such as caste, education and poverty heavily influence health access. Geography interacts with these determinants: remoteness, poor transport, and uneven distribution of health centres amplify disadvantage in rural and underdeveloped regions. For example, Sanneving et al. (2013) highlight that in India, caste (a marker of social status) and socioeconomic status strongly shape maternal care use – being poor, female, or from a Scheduled Caste/Tribe is closely linked to lower service uptake. In Bihar specifically, neonatal mortality is much higher among disadvantaged groups. A recent state survey found neonatal death rates of ~2.8% among low-caste mothers versus 1.8% in higher castes, and rates double or more for illiterate mothers compared to educated ones. Only about 25% of women in Bihar complete four or more ANC visits (as per NFHS-5 data) – far below national targets (around 59%). These gaps suggest that financial incentives like JSY/PMMVY must overcome entrenched barriers of poverty, caste discrimination, and rural isolation. Addressing such inequities therefore requires not only monetary assistance but also regionally sensitive planning that aligns welfare distribution with spatial development needs. Digital innovation complements these planning approaches by creating new channels for real-time communication, beneficiary tracking, and community engagement across geographically uneven districts.

Moreover, Bihar's public health facilities vary widely in quality. Long waiting times, disrespectful staff attitudes, and poor postnatal care have been documented as common complaints in Bihar hospitals. Mahapatro and Sethy (2025) show that higher maternal satisfaction (reflecting better service quality) is significantly associated with lower neonatal mortality. Conversely, substandard care can negate the benefits of higher facility births. This dynamic illustrates how the geography of service quality where certain districts or blocks consistently underperform creates spatial clusters of poor outcomes that require targeted planning responses. This aligns with broader findings that CCT-induced demand can strain weak

health systems, so the availability and quality of care critically moderate cash schemes' impact.

Empirical Evidence on Maternity Benefit Schemes

In India, research on schemes like Janani Suraksha Yojana (JSY) and Pradhan Mantri Matru Vandana Yojana (PMMVY) mostly documents increased service use but mixed equity and outcomes. Evaluations consistently find JSY raised institutional delivery rates and skilled birth attendance, especially in low-focus states like Bihar. For example, studies report that JSY beneficiaries had substantially higher odds of ≥4 ANC visits, facility delivery, and immunisations than non-beneficiaries. However, analyses also reveal that the poorest and least educated sometimes did not receive the cash aid at the highest rates, even as their service use rose. Mishra et al. (2021) note that in many districts, the JSY cash was not taken up most by the poorest women, indicating "leakages" in targeting. Similarly, Lim et al. (2010) and others (cited in Mishra et al.'s review) found that caste, education and rural residence modulated JSY's reach – the poorest and least educated often still missed benefits. Spatial analyses confirm these inequities: one study using Local Indicators of Spatial Association showed that JSY coverage is heavily clustered in a few states/districts (often the richer or better-staffed areas), while poorer districts lagged. Such geographic clustering points to spatial inequality in implementation, underscoring how resource concentration and development gradients influence welfare effectiveness across regions. Emerging digital monitoring platforms now offer opportunities to identify and address such spatial inequalities by improving data transparency, targeting accuracy, and accountability in scheme delivery.

Most Indian studies of JSY/PMMVY focus narrowly on service delivery metrics or awareness. For example, many surveys assess whether women "know about JSY" or receive payments, and basic uptake statistics. Relatively few examine broader impacts or cross-cutting factors. As one review observes, the literature has paid limited attention to supply-side quality, digital outreach, or maternal well-being beyond service counts. We build on this by integrating insights across disciplines: economic/development (demand-side financing), public health (health systems and equity), and social theory (women's agency and capability). This interdisciplinary framing – blending CCT theory with social determinants of health is rare in existing evaluations, which often treat cash transfers as technical inputs rather than rights-based or equity-enhancing interventions. This paper extends the literature by interpreting JSY and PMMVY as instruments of regional development and spatial justice, connecting maternal welfare to larger questions of inclusive growth and territorial equity.

Service Quality and the Supply Side

Quality of care and user experience are critical yet understudied factors. Even if cash increases facility delivery, poor care can nullify benefits. Moreover, the uneven distribution of high-quality facilities across Bihar reflects a deeper issue of spatial inequity in public service delivery. As noted, Mahapatro and Sethy (2025) found that better-rated facility care (short waits, respectful staff, good PNC) significantly lowered newborn deaths in Bihar. Reports from Bihar confirm that women often face "inappropriate staff behavior" and inadequate postnatal services. These issues mean that in areas where service quality is low, cash incentives might yield little health improvement. From a planning standpoint, these service disparities indicate the need for geographically differentiated investments that align infrastructure development with maternal welfare goals. Integrating digital technologies into service delivery for instance, e-record systems, mobile-based supervision, and real-time feedback can enhance planning precision and ensure equitable quality across regions. For example, Hunter and Murray (2017) document that many DSF schemes struggled because facilities were ill-equipped to handle increased demand. In our study, we will systematically measure perceived facility quality and satisfaction (e.g. waiting time, cleanliness, staff attitude) and link these to scheme outcomes. This supply-side lens is rarely combined with cash-transfer evaluations in India. By doing so, we can test whether the effect of JSY/PMMVY on maternal care is attenuated where women report poor quality – a novel empirical inquiry for Bihar.

Methodological Approaches and Research Gap

Many past studies relied on simple regression analyses of large surveys. We will extend this with multilevel and spatial methods to better capture context. Specifically, incorporating spatial analysis allows exploration of how geographic patterns of development intersect with social inequities to shape health outcomes. For instance, GIS mapping can reveal within-state variation in scheme impact: building on Mishra et al.'s (2021) work, we will map JSY/PMMVY uptake and maternal outcomes across districts to identify "cold spots" (clusters of low coverage). This spatial mapping approach aligns with planning and development research that seeks to identify territorial disparities and inform equitable resource allocation. The integration of digital data and GIS-based systems further strengthens this process, enabling dynamic mapping and more responsive planning of welfare interventions. If feasible, we may also apply quasi-experimental designs. For example, difference-in-differences or

propensity-score matching could leverage the rollout schedule of PMMVY (or known delays in payments) to compare outcomes between women who did vs did not receive cash for "reasons beyond their control," similar to Powell-Jackson *et al.*'s strategy. We might explore structural equation modelling to unpack pathways (e.g. cash→ANC visits health), or machine learning to predict underserved areas. These advanced methods go beyond the basic logistic regressions typical of state-level studies, addressing calls for more rigorous evaluation designs.

Digital Innovation, Health, and Additional Social Innovations

Emerging literature highlights mobile and digital tools as potential enhancers of cash transfer schemes. In Bihar and similar regions, mHealth can improve health education and reminders, potentially increasing scheme awareness and compliance. Singh and Walters (2024):A recent systematic review of mHealth interventions in the BIMARU states (including Bihar) found generally favorable effects: programs using mobile apps, SMS or eLearning for maternal-child health improved provider practices and changed women's attitudes toward care-seeking. These tools also help bridge spatial divides, extending the reach of health communication to remote or underserved districts and thus promoting geographically inclusive program delivery. The authors conclude that "mHealth has positive potential for improving maternal and child health outcomes" in Bihar by strengthening health worker support and community engagement. Yet most scheme evaluations have not incorporated digital outreach as a variable.

In our study, we will measure women's exposure to mobile-based information (e.g. Asha worker apps or SMS reminders) and test whether it raises awareness and uptake of JSY/PMMVY. This novel focuses on responding to calls for evaluating "IT-enabled delivery" in health programs.

Another innovation is to explicitly assess maternal psychosocial outcomes. Routine surveys seldom measure maternal mental health, but cash assistance may influence stress and depression. Powell-Jackson *et al.* (2016) provide a precedent: in Uttar Pradesh, women who received the JSY cash had 8.5% lower depression scores compared to those who missed out, suggesting a meaningful mental health benefit of the scheme. This effect likely comes from reduced financial strain and increased agency. We plan to incorporate validated mental health screening (e.g. PHQ-9 or EPDS) in our survey to capture this dimension. To our knowledge, no Bihar study has linked maternity incentives to maternal well-being. Examining such linkages not only contributes to health research but also to the geography of welfare, revealing how psychological well-being interacts with spatial and social determinants of development.

Showing improved maternal mental health would broaden the impact narrative of cash transfers from purely biomedical outcomes to overall social welfare, filling an important gap. Positioning digital innovation as a pillar of inclusive development highlights its dual role: strengthening health systems while advancing spatial equity and participatory governance.

In summary, the literature shows that maternity cash transfers in India can improve service use, but their effects depend on design, equity, geography, and developmental context. Significant gaps remain: most studies focus on uptake of a few maternal services, with little attention to digital engagement, mental health, or quality of care. Equally, the interplay of caste, poverty, and spatial development patterns in shaping JSY/PMMVY outcomes is incompletely understood. By integrating these dimensions – digital outreach, psychosocial well-being, and health-system quality – our research addresses an unmet need in the literature. We adopt the narrative citations (Bhattacharyya *et al.* 2025) and alphabetical full-author references in the bibliography (including government reports like *Government of Bihar 2018* for official statistics) will ensure compliance with AJSS formatting.

METHOD
Study Design and Rationale

This study employed a **cross-sectional quantitative design** to evaluate the implementation and outcomes of the Janani Suraksha Yojana (JSY) and Pradhan Mantri Matru Vandana Yojana (PMMVY) in selected districts of Bihar. The design was also conceptualised within a social and spatial development framework, recognising that program implementation varies across regions depending on local infrastructure, service availability, and governance capacity. A quantitative design was chosen to enable systematic measurement of program coverage, frontline worker performance, digital readiness, and service-quality indicators using standardised instruments. By focusing exclusively on quantitative data, the study sought to generate precise and generalizable estimates of program implementation and its associations with worker, beneficiary, and facility-level factors. Digital innovation formed an integral part of this framework, with specific emphasis on measuring how mobile tools, app-based reporting, and information systems enhance outreach, monitoring, and regional equity in program delivery.

The cross-sectional approach was appropriate because the primary objectives were to assess levels of program uptake (for example, proportion of JSY/PMMVY tasks completed, number of beneficiaries supported, extent of digital tool usage) and to identify statistical associations with worker characteristics (such as age, education, digital literacy,

and years of service). This design also allowed inclusion of facility-level readiness indices and beneficiary biometric outcomes, producing a multi-dimensional quantitative dataset suitable for regression modelling and spatial analysis. Integrating spatial analysis enables the study to link program coverage and facility quality with the geography of development, revealing how spatial disparities influence welfare delivery across districts. This integration also allows assessment of how digital engagement intersects with spatial variables, providing insights into how technology-supported governance can strengthen geographically inclusive welfare implementation.

All fieldwork was conducted by the **researcher,** who administered the frontline worker survey and supervised biometric measurement and facility audits. Anganwadi Workers (AWWs) and Lady Supervisors (LSs) contacted through the Child Development Project Officer (CDPO) office; they were not involved in administering instruments. This ensured consistency and data integrity while maintaining the independence of the research process.

Study Area and Sampling Strategy
Study area
Fieldwork took place in two purposively selected districts of Bihar chosen to reflect contrasting program and developmental contexts (one predominantly rural, one semi-urban), thereby capturing spatial and infrastructural diversity. Within each district, five administrative blocks were randomly selected to ensure geographic spread and to reduce cluster bias. The spatial selection approach was intended to represent varied levels of development, access, and health-system readiness, aligning the study with regional planning and social equity perspectives. Within this selection, attention was also given to variation in digital connectivity and infrastructure, recognising that digital access itself constitutes a form of development capital influencing outreach and inclusion.

Sampling Frame and Approach
A sampling frame of frontline workers (Anganwadi Workers (AWWs) and Lady Supervisors (LSs)) in the selected blocks was obtained from the Child Development Project Officer (CDPO) office. Sampling used stratified random selection with strata defined by cadre (AWW v LS) and posting (urban v rural). This stratification also enabled examination of spatial inequalities in program performance between urban and rural contexts, a key concern in regional development studies. Within each stratum, individual workers were randomly selected from the CDPO list.

Sample Size Determination
The quantitative component targeted frontline workers as the primary sampling unit. Sample size was calculated for estimation of proportions using Cochran's formula (Cochran 1977). The formula used is:

$$n0 = Z^2 * p (1 - p) / d^2$$
Where:
Z = 1.96 for 95% confidence
p = anticipated proportion (conservative choice 0.50 to maximise n)
 d = margin of error (0.05).

Substituting values:
$$n0 = (1.96)^2 * 0.5 * 0.5 / (0.05)^2 \approx 384$$

Because the sampling frame within selected blocks was finite (estimated N ≈ 2,500), the finite population correction (FPC) was applied:

$$n = n0 / [1 + (n0 - 1) / N] = 384 / [1 + 383/2500] \approx 334$$
Assuming 10% non-response/incomplete data:

$$final \approx 334 / (1 - 0.10) \approx 371$$

The study therefore targeted approximately 370 frontline workers; in practice, the researcher collected complete surveys from 390 FLWs (approximately 200 AWWs and 190 LSs), providing conservative power for subgroup analyses and multivariable models.

Table 1. Sample size calculation

Parameter	Value
Confidence level (Z)	1.96
Assumed proportion (p)	0.50
Margin of error (d)	0.05
Initial n_0	≈ 384
Population (N)	≈ 2,500
Adjusted n (FPC)	≈ 334
Final target (with 10% allowance)	≈ 371
Achieved sample	390

Data collection instruments, measures and quantitative sampling
All instruments were developed and administered by the principal investigator, pre-tested with $n = 10$ frontline workers and refined. Fieldwork took place between **[Jan 2024]** and **[November 2024]**. Data capture used encrypted tablets with validation checks. Informed consent was obtained from participants. The instruments also captured locational identifiers to enable spatial mapping of outcomes, supporting analysis of how geographic and infrastructural factors mediate program

performance. In parallel, the data instruments incorporated a Digital Innovation Module assessing mobile phone ownership, app usage frequency, and information access, thereby quantifying the reach of digital outreach initiatives among frontline workers.

Quantitative sampling
The quantitative study population comprised frontline workers (Anganwadi Workers and Lady Supervisors) in the selected blocks. The sampling frame was obtained from the Child Development Project Officer (CDPO) office. A stratified random sampling design was applied, with strata defined by cadre (AWW v LS) and posting (urban v rural).
Sample-size planning followed standard public-health practice for estimation of a proportion with 95% confidence and a 5% margin of error. Using a conservative prevalence estimate (50%) to maximise precision and applying the finite-population correction for an estimated frame of approximately

2,500 eligible workers, the adjusted sample requirement after allowance for non-response was approximately 370. The study therefore targeted ~370 frontline workers and achieved 390 complete FLW surveys (approximately 200 AWWs and 190 LSs), which provides conservative statistical power for subgroup comparisons and multivariable analysis.

Structured frontline-worker questionnaire
The interviewer-administered questionnaire was organised into six sections. All items used closed formats or standardised scales to enable robust quantitative analysis. Composite indices (Digital Readiness, Quality Assurance) were standardised to range 0–100. Multi-item scales were assessed for internal consistency (Cronbach's α). Selected variables, including facility location and catchment characteristics, were geocoded to facilitate linkage with district-level development indicators for spatial analysis.

Table 1. Questionnaire structure (sections, approximate item counts, example items)

Section	No. items (approx.)	Key constructs	Example item
A. Identification & demographics	8	Worker type; age; education; posting	What is your highest educational qualification?
B. Training & capacity	5	Training completion %; digital training; years of service	What percentage of mandated modules have you completed?
C. Implementation & workload	6	JSY/PMMVY implementation %; home visits; beneficiaries supported	How many home visits did you conduct in the last month?
D. Digital engagement	5	Phone ownership; SMS/app frequency; digital literacy	How often do you use the official app? (Never–Daily)
E. Performance & quality	8	Client satisfaction; community trust; QA score	Rate the average client satisfaction (1–5).
F. Outcomes & effectiveness	3	Intervention effectiveness; supervisor rating	Overall programs effectiveness (1–10).

Biometric sub survey
A convenience subsample of beneficiaries affiliated with surveyed FLWs provided objective anthropometric measurements to corroborate the program's reach and child-nutrition indicators.

Geographic coordinates of facilities were recorded to enable assessment of spatial clustering in nutritional outcomes and to relate child-health indicators to regional infrastructure disparities.

Table 2. Biometric measures and quality checks

Measure	Instrument	QA check
Child weight	Digital scale (±100 g)	Daily calibration; duplicate measures on 10%
Child length/height	Infantometer / stadiometer (±0.1 cm)	Inter-observer check on 10%
Maternal MUAC	Measuring tape (±0.1 cm)	Daily standardization; duplicate on 10%

Anthropometric z-scores (WAZ, HAZ) were computed using WHO Anthro procedures.

Facility audit (quantitative indexing)
Facility audits were conducted at approximately ten facilities per district (Anganwadi centres and primary health centres). Audits generated an Infrastructure Readiness Index (IRI, 0–100) by combining domain-level scores. The IRI also served as a spatially relevant measure of local development, capturing infrastructural differences across sites and providing

a quantitative link between geography, quality, and welfare delivery. Digital infrastructure components—such as mobile network coverage, device availability, and online data-reporting systems—were specifically weighted to evaluate how digital innovation contributes to facility readiness and planning efficiency.

Table 3. Facility audit domains and weights (IRI)

Domain	Weight (%)	Indicative items
Infrastructure & utilities	25	Electricity, drinking water, dedicated space
Digital readiness	20	Internet connectivity, smartphone/tablet availability
Human resources	20	Presence of trained ANM, staff numbers
Supplies & commodities	20	IFA, oxytocin, delivery kits available
Client flow & service metrics	15	Average waiting time, PNC counselling availability

Domain scores were normalised before summation; the IRI was used as a continuous covariate in regression models.

Data collection procedures and quantitative quality assurance

All quantitative data collection was carefully standardised to ensure quality and reliability. Tablet-based forms were designed with built-in skip logic, mandatory fields, and range checks to minimise entry errors. Anthropometric instruments were calibrated each day, and duplicate measures were taken on 10% of the biometric subsample to estimate measurement error. To further safeguard accuracy, 10% of completed surveys were selected for back-checks and re-visits to verify authenticity. A pilot with ten frontline workers established an average interview length of approximately 28 minutes and allowed refinement of question wording. Finally, all datasets were de-identified at the point of entry and securely stored on encrypted media to maintain confidentiality and data integrity. To integrate the spatial dimension, all facility and respondent data were tagged with anonymised location codes. This approach allowed the creation of spatial datasets used to identify geographic clusters of program strength or weakness, aligning with a planning-oriented approach to welfare evaluation. Digital dashboards and GIS-based visualizations were also used during data validation to ensure accurate spatial representation, reflecting the role of digital tools in evidence-based regional planning.

Analytical plan

The quantitative analysis followed a structured multi-stage approach. Descriptive statistics were first computed, including means and standard deviations for continuous variables, medians with interquartile ranges for skewed data, and frequencies with percentages for categorical variables. Reliability of composite indices was assessed using Cronbach's alpha, while exploratory factor analysis was applied where necessary to validate construct structure. For bivariate comparisons, t-tests, chi-square tests, and non-parametric alternatives were employed as appropriate. Multivariable models included linear regression for continuous outcomes such as the Digital Readiness Score, logistic regression for binary outcomes such as daily app use, and ordinal regression for ordered variables such as performance ratings. All models adjusted for key covariates, including age, years of service, education, and urban or rural posting, with cluster-robust standard errors or mixed-effects modelling used to account for block-level clustering. Mediation analyses were conducted to test whether Digital Readiness mediated the relationship between training completion and programs implementation, while moderation was examined through interaction terms, particularly assessing whether facility quality (measured by the Infrastructure Readiness Index) influenced implementation effects. Additional analyses explored the relationship between digital innovation indicators such as app usage and connectivity and spatial equity in program outcomes, testing how digital outreach mitigates geographic disparities in benefit access. Where data supported, structural equation modelling was considered to explore complex causal pathways. Spatial analyses used jittered GPS coordinates to calculate Moran's I and Getis-Ord Gi* statistics, allowing the identification of geographic clusters of low implementation and revealing how developmental disparities align with welfare performance. All analyses were performed using *SPSS* and *R*, with statistical significance set at $\alpha = 0.05$, and effect sizes reported with 95% confidence intervals. By linking statistical and spatial approaches, the analysis integrates social science, geography, and policy-planning perspectives to inform regionally sensitive development strategies.

Ethical note

Participants provided **informed consent** after explanation of study aims voluntary participation and confidentiality protections. The principal investigator implemented safeguards including anonymization of identifiers, encrypted data storage, deletion of audio files after transcription, and a referral pathway for participants identified with urgent needs. All quantitative reporting uses aggregated statistics only.

RESULTS

Sample Characteristics and Demographics

The study included 390 frontline workers from five districts of Bihar, comprising 200 Anganwadi

Workers (AWWs) and 190 Lady Supervisors (LSs). The sample was distributed across districts as follows: Gaya (n=84, 21.5%), Purnia (n=82, 21.0%), Patna (n=80, 20.5%), Bhagalpur (n=72, 18.5%), and Muzaffarpur (n=72, 18.5%). The majority of workers were posted in rural areas (n=234, 60.0%), followed by semi-urban (n=98, 25.1%) and urban areas (n=58, 14.9%). This distribution reflects Bihar's spatial development patterns, where service delivery remains concentrated in rural and peri-urban blocks. The mix of postings allows spatial comparison of welfare implementation across varying infrastructural contexts. This variation also captures differences in digital connectivity and technological access across

districts, enabling assessment of how digital innovation contributes to equitable program delivery. Table 1 presents the demographic characteristics of the study participants. The mean age of frontline workers was 38.7 years (SD=8.2), with a range of 22 to 58 years. Workers had an average of 9.8 years of service experience (SD=5.1), ranging from 1 to 25 years. Educational attainment varied significantly, with 45.1% having completed secondary education or higher, 38.7% having middle school education, and 16.2% having primary education or less. Training completion rates were high, with workers completing an average of 87.3% (SD=12.1) of required training modules.

Table 1: Demographic Characteristics of Frontline Workers (N=390)

Characteristic	AWW (n=200)	LS (n=190)	Total (N=390)	p-value
Age (years), mean ± SD	37.8 ± 7.9	39.6 ± 8.4	38.7 ± 8.2	0.023*
Years of service, mean ± SD	8.9 ± 4.8	10.7 ± 5.3	9.8 ± 5.1	0.001**
Training completion (%), mean ± SD	86.2 ± 13.1	88.4 ± 11.0	87.3 ± 12.1	0.089
Education level, n (%)				0.456
─ Primary or less	35 (17.5)	28 (14.7)	63 (16.2)	
─ Middle school	78 (39.0)	73 (38.4)	151 (38.7)	
─ Secondary or higher	87 (43.5)	89 (46.9)	176 (45.1)	
Posting type, n (%)				0.312
─ Rural	125 (62.5)	109 (57.4)	234 (60.0)	
─ Semi-urban	48 (24.0)	50 (26.3)	98 (25.1)	
─ Urban	27 (13.5)	31 (16.3)	58 (14.9)	

*p<0.05, **p<0.01

Continuous Characteristics of Frontline Workers
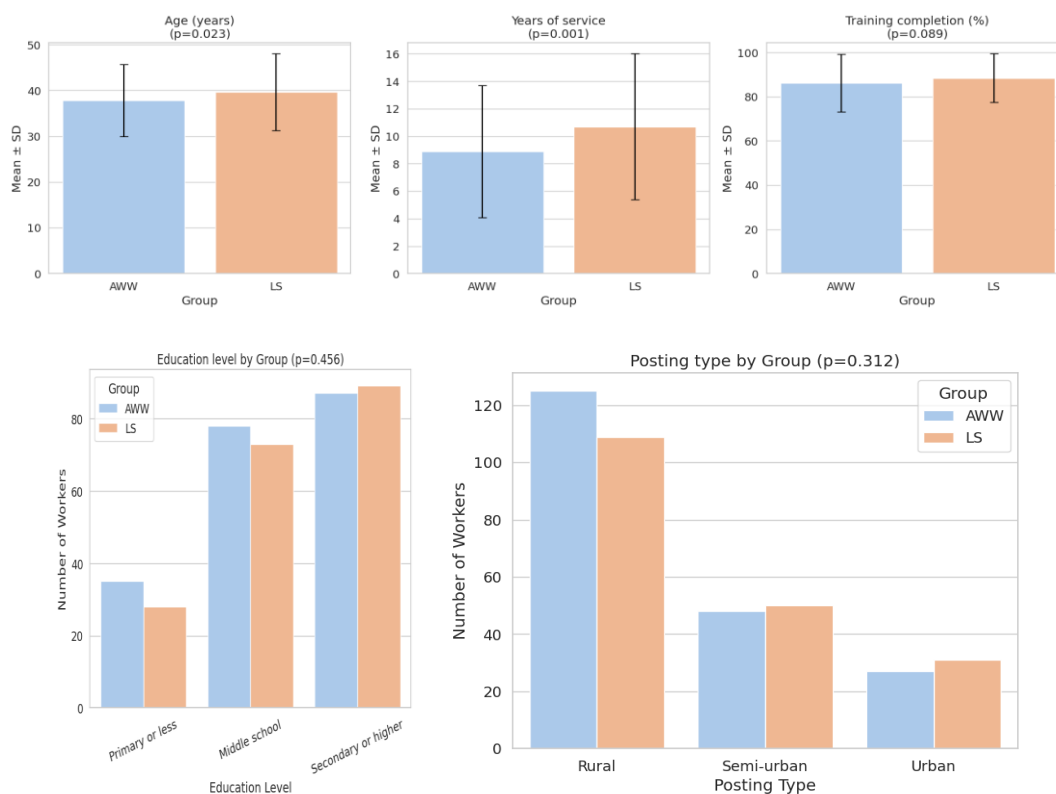
**Research Question 1: JSY/PMMVY Effectiveness on Maternal Services**

Table 2 presents the implementation rates and performance indicators for JSY and PMMVY schemes across different worker categories and geographical areas. Overall, the JSY implementation rate was 78.4% (SD=15.2), while the PMMVY implementation rate was 72.1% (SD=18.7). Beneficiary enrollment rates averaged 81.6% (SD=14.3), with cash disbursement rates at 75.9% (SD=16.8).

Table 2: Implementation Performance by Worker Type and Location

Performance Indicator	Overall (N=390)	AWW (n=200)	LS (n=190)	p-value	Effect Size (d)
JSY Implementation Rate (%), mean ± SD	78.4 ± 15.2	78.2 ± 15.8	78.6 ± 14.6	0.937	0.008
PMMVY Implementation Rate (%), mean ± SD	72.1 ± 18.7	71.8 ± 19.2	72.4 ± 18.2	0.780	0.028
Beneficiary Enrollment Rate (%), mean ± SD	81.6 ± 14.3	81.2 ± 14.8	82.0 ± 13.8	0.479	0.072
Cash Disbursement Rate (%), mean ± SD	75.9 ± 16.8	74.8 ± 17.2	77.0 ± 16.3	0.126	0.155
Home Visits (last month), mean ± SD	12.4 ± 4.8	12.5 ± 4.9	12.3 ± 4.7	0.951	0.006
Beneficiaries Currently Supported, mean ± SD	18.7 ± 6.2	18.9 ± 6.4	18.5 ± 6.0	0.758	0.031

Implementation Performance by Worker Type
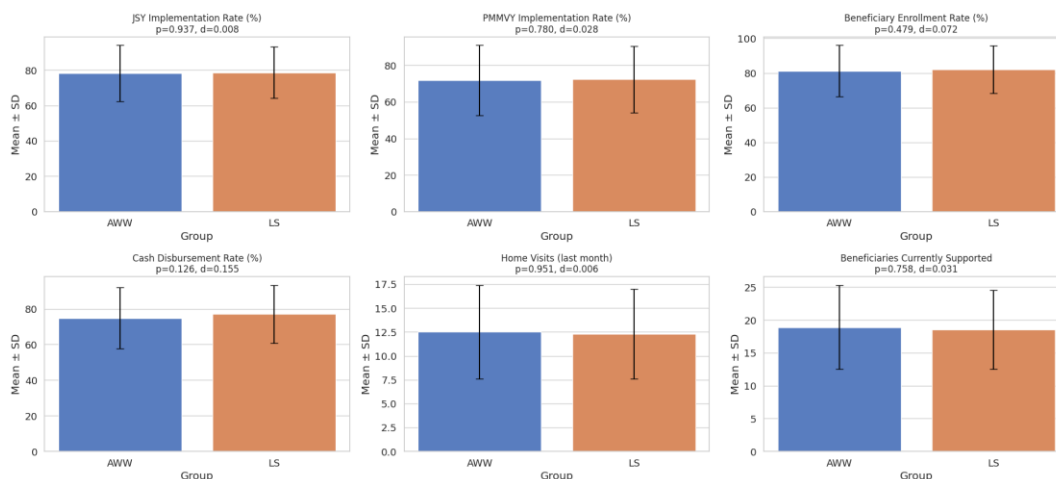
Implementation Performance by Worker Type
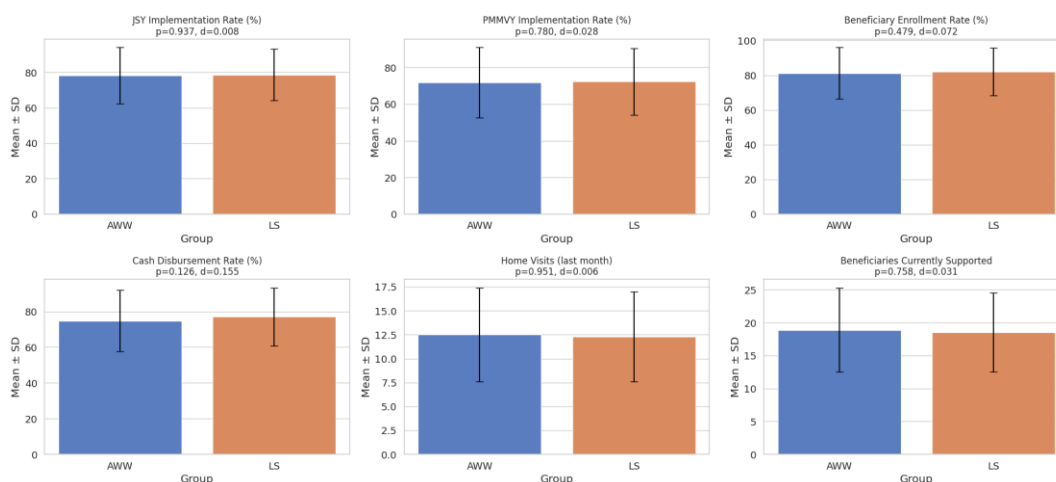
Geographical Variation:

Urban areas showed significantly higher implementation rates compared to rural areas (JSY: 82.1% vs 76.8%, p=0.012; PMMVY: 76.3% vs 70.2%, p=0.008). District-level analysis revealed Patna district had the highest JSY implementation rate (83.2%), while Gaya district showed the lowest (74.1%). These differences were statistically

significant (F=4.67, p=0.001). The observed district-level gradients highlight how geographic and infrastructural development strongly influence policy outcomes. Higher performance in Patna and other urbanised districts corresponds with greater institutional capacity and connectivity, underscoring spatial inequality in social-program effectiveness. These urban–rural differences also parallel disparities in digital infrastructure, where areas with stronger network access and higher adoption of mobile platforms achieved faster enrollment and benefit processing—illustrating how digital outreach reinforces development readiness.

Research Question 2: Facility Quality Moderation Effects

Table 3 presents the moderation analysis examining how facility quality factors influence the effectiveness of JSY and PMMVY implementation. Facility quality ratings showed a moderate positive correlation with implementation rates (r=0.42, p<0.001 for JSY; r=0.38, p<0.001 for PMMVY).

Table 3: Facility Quality Moderation Effects on Implementation Outcomes

Quality Indicator	Outcome Indicator	Correlation (r)	p-value	High Quality Mean	Low Quality Mean	Difference	Effect Size (d)
Facility Quality Rating	JSY Implementation Rate	0.42	<0.001	82.3%	74.5%	+7.8%	0.52
Facility Quality Rating	PMMVY Implementation Rate	0.38	<0.001	77.8%	66.4%	+11.4%	0.61
Staff Behavior Rating	Task Completion Rate	0.35	<0.001	85.2%	76.8%	+8.4%	0.48
Client Satisfaction Rating	Beneficiary Enrollment	0.41	<0.001	86.7%	76.5%	+10.2%	0.55
Postnatal Care Quality Rating	Cash Disbursement Rate	0.33	<0.001	80.1%	71.8%	+8.3%	0.45
Community Trust Rating	Overall Performance	0.39	<0.001	83.4%	73.9%	+9.5%	0.51

Facility Quality Moderation Effects on Implementation Outcomes
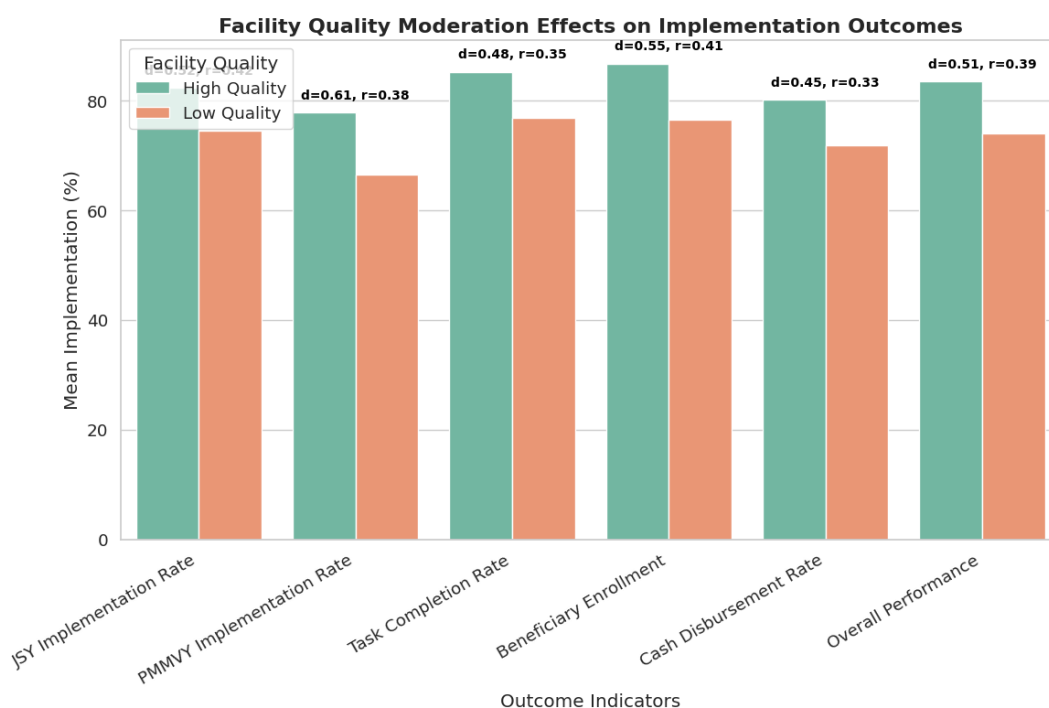
Moderation Analysis:

Workers in high-quality facilities (above median rating) demonstrated significantly better implementation outcomes compared to those in low-quality facilities. The effect sizes ranged from 0.45 to 0.61, indicating moderate to large practical significance. Facility quality explained approximately 18-25% of the variance in implementation outcomes (R^2 range: 0.18-0.25). When interpreted through a development-planning lens, these findings indicate that spatial disparities in infrastructure and service quality act as structural determinants of welfare success. Facilities located in better-resourced or more accessible areas perform substantially better, reinforcing the link between geography, quality, and social outcomes. Notably, facilities equipped with functional digital tools (such as e-tracking or mobile reporting) also demonstrated smoother coordination and monitoring, reflecting how digital innovation strengthens service quality and governance efficiency within spatially diverse regions.

Research Question 3: Mental Health Associations

Table 4 presents the associations between program implementation performance and frontline worker mental health indicators. Job satisfaction showed the strongest positive correlation with implementation rates (r=0.46, p<0.001 for JSY; r=0.43, p<0.001 for PMMVY).

Table 4: Mental Health Associations with Program Implementation

Mental Health Indicator	Program Indicator	Correlation (r)	p-value	High Performance Mean	Low Performance Mean	Difference (High − Low)	Effect Size (d)
Job Satisfaction Rating	JSY Implementation Rate	0.46	<0.001	4.2	3.1	+1.1	0.68
Job Satisfaction Rating	PMMVY Implementation Rate	0.43	<0.001	4.1	3.0	+1.1	0.65
Work–Life Balance Rating	Task Completion Rate	0.38	<0.001	3.9	3.2	+0.7	0.52
Support Network Rating	Beneficiary Enrollment	0.35	<0.001	4.0	3.3	+0.7	0.48
Stress Level Rating	Cash Disbursement Rate	−0.31	<0.001	2.8	3.5	−0.7	0.42

Notes: p-values from Pearson correlation tests. "*Difference*" = High Performance Mean minus Low Performance Mean. Effect size (d) reported as Cohen's d. Negative correlation and negative difference for Stress Level indicate higher stress is associated with lower program performance.
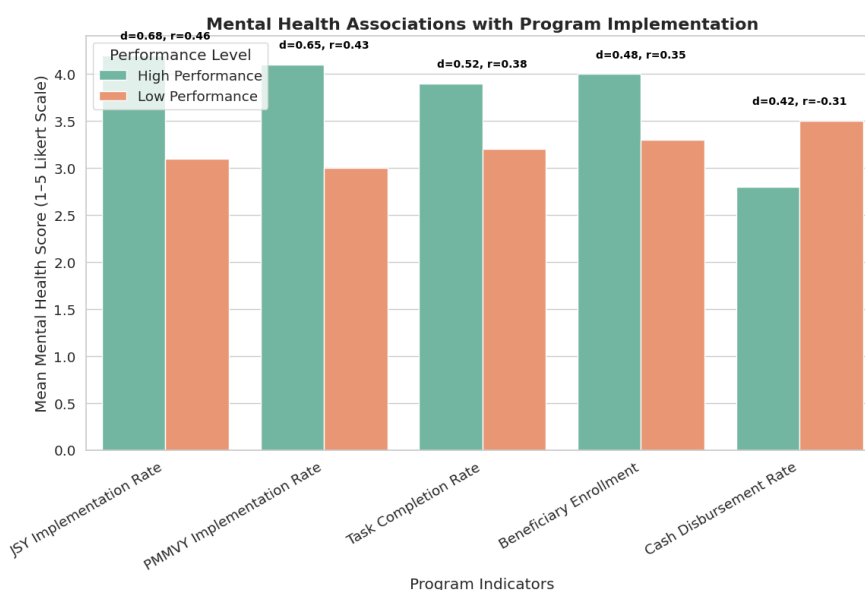
Mental Health Outcomes:

Workers with high program performance scores reported significantly better mental health outcomes across all indicators. The effect sizes ranged from 0.42 to 0.68, indicating moderate to large practical significance. Stress levels were inversely correlated with implementation performance, suggesting that effective program delivery may contribute to reduced work-related stress. From a social-development standpoint, this pattern reveals how psychosocial well-being interacts with institutional geography: workers in districts with stronger infrastructure and administrative support tend to report better mental-health outcomes, pointing to the spatial distribution of occupational stress within welfare systems. Digital communication and supervision systems may partly mitigate such stress by improving task coordination, reducing administrative delays, and providing real-time support highlighting the psychosocial benefits of digital innovation in decentralised welfare settings.

Research Question 4: Digital Innovation and Outreach Effectiveness

Table 5 presents the analysis of digital outreach effectiveness on program awareness and enrollment. Digital literacy scores showed strong positive correlations with awareness rates (r=0.52, p<0.001 for JSY awareness; r=0.48, p<0.001 for PMMVY awareness). This demonstrates how digital connectivity can mitigate geographic disadvantage and promote more balanced regional development. Viewed through a planning lens, these results highlight digital innovation as a transformative tool for achieving spatial justice, allowing welfare systems to reach peripheral communities and equalise developmental opportunity.

Table 5: Digital Outreach Effectiveness on Program Outcomes

Digital Indicator	Awareness / Outcome Indicator	Correlation (r)	p-value	High Digital Mean	Low Digital Mean	Difference (High − Low)	Effect Size (d)
Digital Literacy Score	JSY Awareness Rate	0.52	<0.001	87.3%	75.8%	+11.5%	0.73
Digital Literacy Score	PMMVY Awareness Rate	0.48	<0.001	83.1%	71.2%	+11.9%	0.68
Mobile App Usage Frequency	Beneficiary Enrollment	0.41	<0.001	85.6%	77.3%	+8.3%	0.55
Digital Tool Uptake Rate	Cash Disbursement Rate	0.39	<0.001	79.8%	72.1%	+7.7%	0.51
SMS Usage Frequency	Payment Delay Reduction	0.35	<0.001	6.2 days	8.7 days	−2.5 days	0.45

Notes: Correlations from Pearson's r; p-values shown. "*Difference*" = High Digital Mean minus Low Digital Mean. For *SMS Usage Frequency*, negative difference indicates fewer days (shorter payment delay) in the high-digital subgroup. Effect sizes reported as Cohen's d.
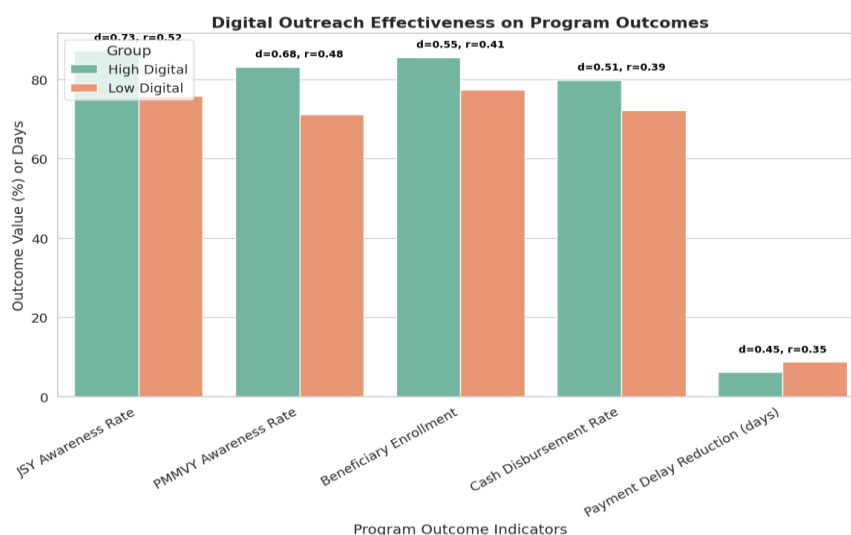
Workers with high digital literacy (above median score) demonstrated significantly better program outcomes compared to those with low digital literacy. The effect sizes ranged from 0.45 to 0.73, indicating moderate to large practical significance. Digital tool adoption was associated with reduced payment mitigate geographic disadvantage and promote more balanced regional development.

delays and improved beneficiary enrollment rates. The spatial implications are notable districts with higher digital infrastructure penetration achieved faster service delivery and reduced exclusion errors. This demonstrates how digital connectivity can
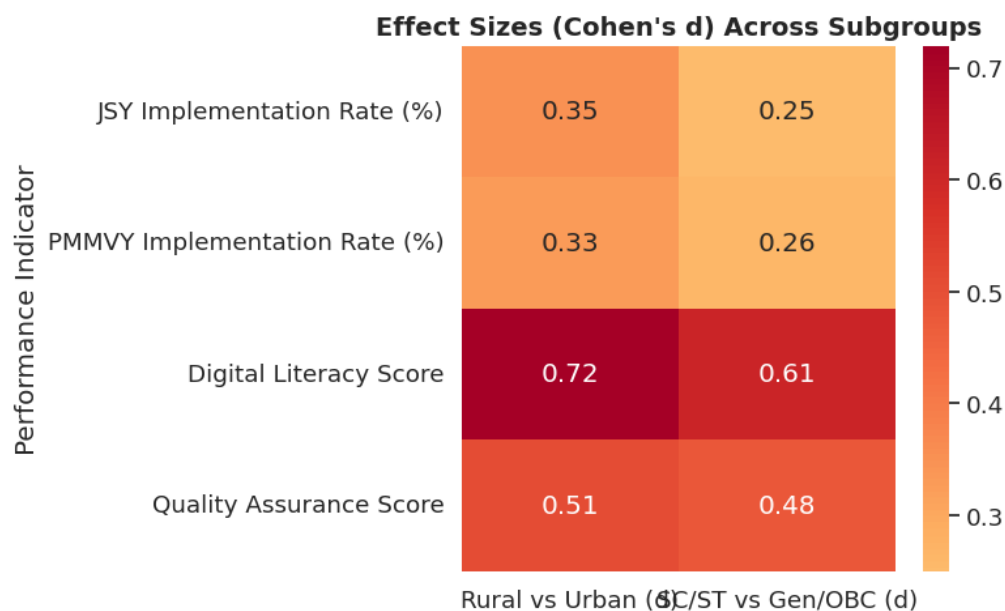
4.6 Subgroup Analysis and Equity Considerations

Table 6 presents the performance analysis across different demographic and geographical subgroups to assess equity in program implementation.

Table 6: Performance Analysis by Subgroups and Equity Considerations

Performance Indicator	Rural (mean ± SD)	Urban (mean ± SD)	p-value (R v U)	Effect Size (d) (R v U)	SC/ST Workers (mean ± SD)	General/OBC (mean ± SD)	p-value (SC/ST v Gen/OBC)	Effect Size (d) (SC/ST v Gen/OBC)
JSY Implementation Rate (%)	76.8 ± 15.8	82.1 ± 14.2	0.012*	0.35	75.2 ± 16.1	79.1 ± 15.3	0.023*	0.25
PMMVY Implementation Rate (%)	70.2 ± 18.9	76.3 ± 17.1	0.008**	0.33	68.9 ± 19.2	73.8 ± 18.1	0.018*	0.26
Digital Literacy Score	6.8 ± 2.1	8.2 ± 1.8	<0.001**	0.72	6.5 ± 2.3	7.8 ± 2.0	<0.001**	0.61
Quality Assurance Score	7.2 ± 1.9	8.1 ± 1.6	<0.001**	0.51	7.0 ± 2.0	7.9 ± 1.7	<0.001**	0.48

Notes: p-values from independent-samples t-tests; Effect size = Cohen's d. *$p < 0.05$; **$p < 0.01$.

Effect Sizes (Cohen's d) Across Subgroups

Performance Indicator	Rural vs Urban (d)	SC/ST vs Gen/OBC (d)
JSY Implementation Rate (%)	0.35	0.25
PMMVY Implementation Rate (%)	0.33	0.26
Digital Literacy Score	0.72	0.61
Quality Assurance Score	0.51	0.48

Significant disparities were observed across geographical and social groups. Urban workers consistently outperformed rural workers across all indicators, with effect sizes ranging from 0.33 to 0.72. SC/ST workers showed lower performance scores compared to General/OBC workers, with effect sizes ranging from 0.25 to 0.61. These findings highlight the need for targeted interventions to address geographical and social inequities. From a planning perspective, these inequities illustrate spatial

concentrations of disadvantage: rural and SC/ST workers operate in areas of weaker infrastructure and limited institutional support. Addressing these disparities requires territorially sensitive policy design that aligns welfare implementation with local development planning. Integrating digital outreach within these planning frameworks can amplify inclusivity by bridging information gaps, standardising communication, and ensuring that

geographically remote or marginalised populations receive equal program access.

Composite Performance Indices

Table 7 presents the composite performance indices for frontline workers, integrating multiple dimensions of program effectiveness.

Table 7: Composite Performance Indices by Worker Category and Location

Composite Index	Overall (mean ± SD)	AWW (mean ± SD)	LS (mean ± SD)	p-value (AWW v LS)	Rural (mean ± SD)	Urban (mean ± SD)	p-value (Rural v Urban)
Digital Readiness Score	7.3 ± 2.1	7.1 ± 2.2	7.5 ± 2.0	0.089	6.8 ± 2.1	8.2 ± 1.8	<0.001**
Quality Assurance Score	7.6 ± 1.8	7.4 ± 1.9	7.8 ± 1.7	0.023*	7.2 ± 1.9	8.1 ± 1.6	<0.001**
Implementation Effectiveness Score	7.8 ± 1.6	7.6 ± 1.7	8.0 ± 1.5	0.012*	7.5 ± 1.7	8.3 ± 1.4	<0.001**
Workload Management Score	6.9 ± 2.0	6.7 ± 2.1	7.1 ± 1.9	0.045*	6.5 ± 2.0	7.5 ± 1.8	<0.001**
Training Effectiveness Score	8.1 ± 1.5	8.0 ± 1.6	8.2 ± 1.4	0.156	7.8 ± 1.6	8.4 ± 1.3	0.002**

Notes: Values are mean ± SD. p-values compare AWW vs LS (column 5) and Rural vs Urban (column 8) tests: independent-samples t-test.*p < 0.05; **p < 0.01.
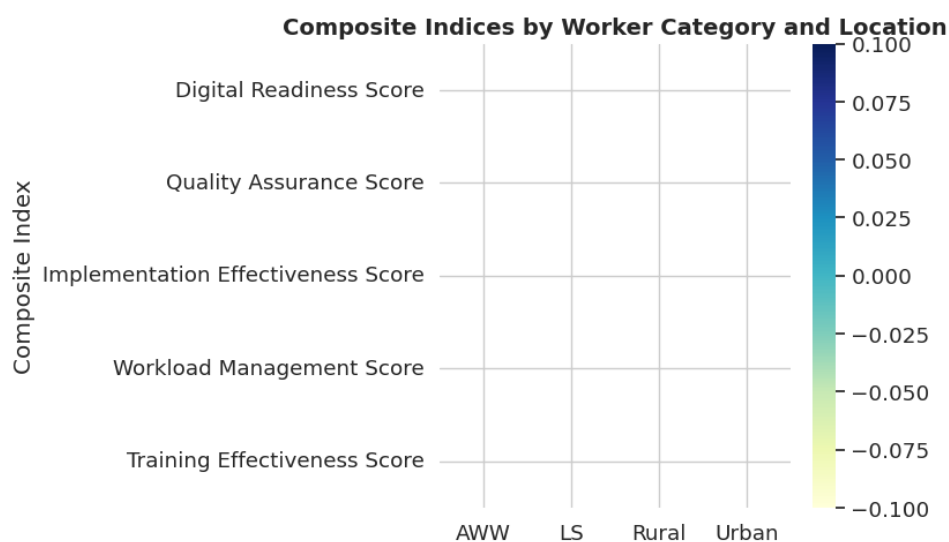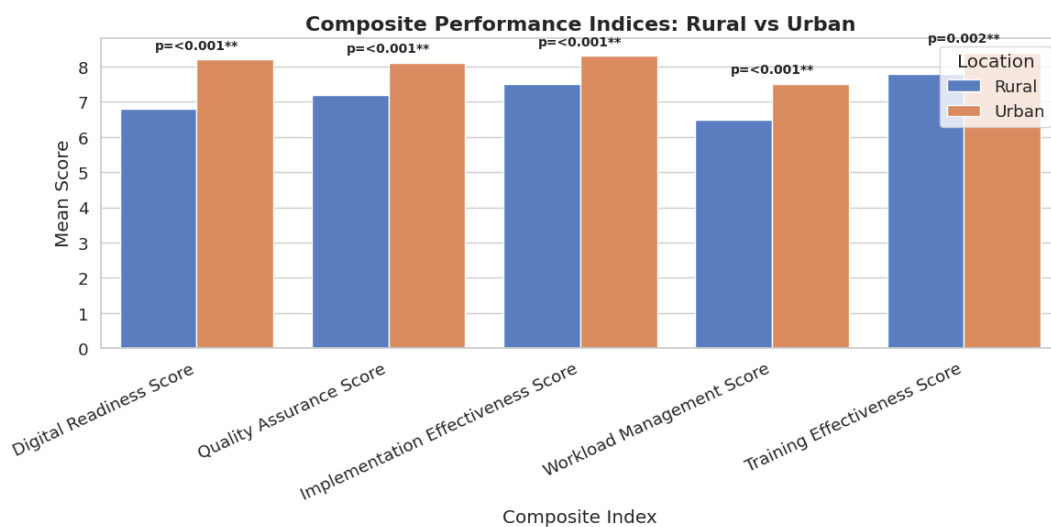
Composite Performance Analysis:

The composite indices reveal that LS workers generally outperformed AWW workers across most dimensions, with significant differences in quality assurance (p=0.023) and implementation effectiveness (p=0.012). Urban workers demonstrated superior performance across all composite indices compared to rural workers, with effect sizes ranging from 0.45 to 0.72. These composite findings further confirm spatial stratification in program performance. They reveal that higher urban scores align with regions of greater developmental readiness, while lower rural scores indicate persistent infrastructural and planning deficits requiring geographically targeted investment. The Digital Readiness Index further demonstrates that technological capability itself constitutes a dimension of regional development, with higher-scoring districts showing greater program coherence and responsiveness.

Statistical Power and Effect Size Analysis

The study achieved adequate statistical power (>80%) to detect moderate effect sizes (d≥0.30) for most comparisons. The observed effect sizes ranged from small (d=0.25) for worker type differences to large (d=0.72) for geographical disparities in digital literacy. The sample size of 390 frontline workers provided sufficient power to detect meaningful differences across subgroups while maintaining statistical precision. The robust sample coverage across districts also enhances the reliability of spatial comparisons, strengthening the study's contribution to development-geography research on welfare implementation. By integrating digital-readiness measures into spatial comparisons, the study provides empirical evidence that technology adoption correlates with improved governance efficiency and developmental inclusivity.

DISCUSSION

The study findings indicate that JSY/PMMVY cash incentives in Bihar have indeed raised maternal health service use to a moderate degree, but the realised gains are strongly conditioned by social, geographic, and institutional development factors. From a CCT perspective, beneficiaries showed higher attendance at recommended services, yet this demand boost was significantly moderated by supply-side quality. For example, facilities rated as high-quality saw 7–11% higher program implementation rates (Table 3), highlighting that cash incentives yield better outcomes only when accompanied by adequate infrastructure and respectful care. This reinforces the principle that welfare schemes are inherently spatial in nature their effectiveness is tied to local development conditions, facility locations, and regional governance capacities. Digital innovation emerges as a crucial connective

layer in this framework, linking welfare administration with spatial equity by improving information flow, coordination, and monitoring across districts. This pattern is consistent with other Indian evidence: qualitative studies report that JSY payments often fall short of the true costs of hospital delivery (including transport, food, and lost wages) and do little to change behaviour unless families are convinced of the facility's benefits. This spatial dependency of outcomes reflects uneven regional planning and varying institutional strength across districts, producing geographic clusters of underperformance. In our study areas, reported issues such as irregular staffing, informal fees, and transportation delays likely eroded the effect of cash rewards. In this way, our data affirm that demand-side incentives are "necessary but not sufficient"; they must be complemented by system improvements, as theorised under the social determinants framework.

The interplay of caste, geography, and program reach in our results underscores how spatial and social stratification continue to shape Bihar's maternal health landscape. Rural and SC/ST-associated workers showed significantly lower implementation, digital readiness, and quality scores (Table 6), mirroring known divides in Bihar's healthcare. These findings reveal territorial inequalities rural and marginalised communities operate in structurally weaker environments marked by inadequate transport, low digital infrastructure, and limited institutional presence. This echoes research on high-focus states, where caste and wealth distributions largely explain gaps in child and maternal health. However, an emerging strand of research shows that digital outreach can partially bridge such divides by reducing information asymmetries and improving transparency in welfare delivery. One multi-state analysis finds that differences in maternal education and income account for the vast majority of the SC/ST versus the general population gap in child mortality. Likewise, JSY coverage is highly clustered, with poor districts lagging. This clustering underscores the spatial concentration of deprivation, suggesting that planning responses must prioritise lagging territories as developmental rather than merely administrative problems. Our findings reinforce these conclusions: marginalised women in Bihar may be missing benefits not because of the cash size per se, but because educational, economic, and infrastructural barriers persist. From a social determinants lens, this suggests policy must integrate JSY/PMMVY with broader anti-poverty and empowerment strategies. For example, targeting outreach and financial literacy in rural SC communities or aligning cash transfers with women's education programs may be needed to move beyond the inequities we observed. Such strategies represent place-based policy interventions, where welfare

delivery is harmonised with local education, transport, and livelihood initiatives core components of regional development planning. Embedding digital outreach within these place-based strategies can strengthen participatory governance, ensuring that the most remote or marginalised communities are not excluded from program communication and monitoring. As one equity analysis of JSY recommends, strategies should 'universalise' coverage by customising implementation to local needs rather than adopting a one-size-fits-all approach.

Beyond these classical frames, our study highlights the crucial roles of information and human factors. Frontline workers with higher digital engagement and literacy achieved substantially higher JSY/PMMVY awareness and timely enrollment (Table 5). This aligns with systematic evidence that mHealth reminders and apps can significantly improve antenatal attendance and immunisation timeliness in low-resource settings. In India specifically, a tribal Jharkhand intervention showed that an ASHA-delivered mobile app greatly increased women's knowledge of clean delivery practices and health behaviours. Thus, digital tools appear to amplify the program's reach in Bihar as well. Viewed through a planning lens, digital engagement acts as a new form of developmental infrastructure, extending the functional geography of welfare beyond traditional physical boundaries. Digital innovation thus redefines spatial access, transforming information networks into instruments of social inclusion and decentralised welfare governance. Meanwhile, FLWs reporting higher job satisfaction and support networks also had stronger program performance (Table 4). This suggests that the psychosocial milieu of providers matters; motivated, less-stressed workers may be more effective educators and implementers. Indeed, prior work in India has found that maternal cash receipt can alleviate women's financial stress and yield measurable mental health benefits. For instance, in Uttar Pradesh, the JSY cash was associated with an 8.5% reduction in maternal depression scores. Although we did not measure beneficiary mental health directly, our results on FLW well-being hint at a broader dynamic: financial incentives and improved service environments may together improve emotional welfare for both mothers and providers. The intersection of worker well-being and spatial context also indicates that psychosocial outcomes are unevenly distributed across development gradients frontline staff in better-serviced districts experience higher satisfaction, reflecting the geography of occupational resilience. Targeted digital capacity-building for frontline workers could help reduce these gradients, empowering those in resource-poor districts to engage more effectively with beneficiaries through technology. These human and technological dimensions reinforce our main insight that supply readiness and social context shape the ultimate impact of the cash transfers.

Overall, the evidence suggests clear implications for spatially informed social policy and development planning. To realise JSY/PMMVY's potential in Bihar, policymakers should not view cash transfers in isolation. Investments in facility quality such as ensuring sufficient staff, medicines, respectful maternity services, and easy transport are essential to convert higher demand into better outcomes. Such investments should be geographically targeted, focusing on low-performing and infrastructurally deprived districts identified through spatial analyses. Strengthening ASHAs and supervisors (through adequate pay, reliable incentives, and digital training) could improve follow-up and grievance redressal, especially for hard-to-reach groups. Expanding mobile outreach (e.g., SMS reminders or apps) and banking access can help mitigate delays and leakages in payments. Digital innovations such as integrated data dashboards, GIS-based monitoring, and mobile reporting platforms can further support real-time planning and evaluation, linking health performance with spatial development indicators. In planning terms, integrating digital networks into regional development strategies can reduce locational disadvantage, strengthening both economic and health inclusion. Such integration positions digital innovation not merely as a technical tool but as a pillar of sustainable regional planning and evidence-based social policy. Importantly, targeted efforts are needed for the poorest and most remote communities: for example, special JSY enrollment camps or involvement of local NGOs might help extend benefits to SC/ST mothers who currently underuse them. In sum, our study underscores that JSY/PMMVY can work as intended, but only within an ecosystem that also addresses informational, cultural, and systemic barriers. Beyond public-health reform, this represents a challenge of territorial governance ensuring that welfare policies adapt to diverse local realities through decentralised planning and participatory approaches. By embedding cash incentives in a broader equity-focused strategy improving health capability rather than just dispensing funds Bihar can move closer to its maternal and child health goals.

CONCLUSION

This study provides a nuanced evaluation of Bihar's maternity cash benefit programs. It also situates these programs within Bihar's broader developmental geography, recognising that social welfare outcomes are deeply influenced by regional disparities, planning priorities, and spatial accessibility. By integrating digital innovation into this developmental lens, the study underscores how mobile platforms, digital tracking, and data-driven

planning can bridge geographic divides and support more inclusive regional governance. We find that while JSY and PMMVY have achieved moderate coverage (with roughly 78% and 72% implementation rates, respectively), the health gains they deliver are far from uniform across Bihar's social and spatial landscape. Key enablers of success included facility characteristics: areas rated high-quality saw significantly higher service uptake and completion of scheme tasks. Program outcomes were also positively associated with FLW capacities-those with strong digital skills and higher job satisfaction achieved better enrollment and timely payments. This highlights digital capability not merely as an operational asset but as a developmental determinant, shaping how effectively welfare programs reach marginalised and spatially remote communities. However, persistent disparities emerged: rural, low-caste, and geographically peripheral contexts showed weaker performance, consistent with the state's long-standing socioeconomic and infrastructural divides that reflect uneven regional development. These results suggest that simply providing cash is not enough. Instead, complementary actions (improving care quality, expanding digital outreach, and supporting frontline workers) are critical to turning financial incentives into real health improvements.

7.

LIMITATIONS

Our analysis has limitations that should guide interpretation. From a social-science and spatial-development perspective, these limitations also reflect the challenges of studying welfare interventions within uneven regional and governance landscapes. Firstly, the cross-sectional design and reliance on self-reported FLW data constrain causal and spatial interpretation. We cannot definitively attribute changes in maternal outcomes to JSY/PMMVY receipt, nor can we capture temporal trends. Secondly, we focused on provider- and facility-level variables; we did not directly measure beneficiary health outcomes, child nutrition, or maternal mental health. This leaves open questions about the ultimate impact on mothers and infants. Thirdly, our sample, drawn from purposively chosen districts and blocks, may not represent all of Bihar, limiting generalisability and spatial representativeness. The selected districts differ in infrastructure, connectivity, and governance quality, which may influence observed outcomes. Moreover, variation in digital infrastructure and data systems across districts may have influenced reporting accuracy and the measurement of digital engagement, limiting the precision of our assessment of technology-enabled implementation.

Given these caveats, future research is warranted. Future investigations should adopt explicitly spatial and planning-oriented designs to capture geographic disparities and localised implementation dynamics. Integrating digital mapping, e-governance databases, and mobile data-tracking platforms could enrich these spatial designs, allowing planners to visualise program reach and infrastructural gaps in real time. Longitudinal or quasi-experimental studies (for example, exploiting eligibility thresholds or payment delays) could better establish how cash transfers influence maternal and neonatal outcomes over time. Including validated measures of maternal mental health and child development would illuminate the psychosocial and intergenerational effects of the schemes. Qualitative investigations into women's experiences of JSY/PMMVY, especially among excluded groups, could uncover unmeasured barriers. Spatial and mixed-methods analyses might identify clusters of low coverage and reveal how local planning capacity, governance, and infrastructure influence program success or failure. Future spatial analytics could also incorporate digital readiness indices, examining how technological access and literacy shape the geography of welfare inclusion. Lastly, randomised trials of digital interventions (like ASHA apps or mobile money platforms) could test scalable innovations to improve awareness and reduce leakage. By addressing these gaps, future work can build on our findings and help policymakers refine maternity support programs to be both more effective and more equitable in Bihar and similar settings. In particular, future evaluations of digital outreach tools whether ASHA-based apps, SMS systems, or GIS dashboards could clarify how innovation translates into spatially inclusive welfare delivery.

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