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The Social Epidemiology of the Digital Health Divide: Mixed-Methods Evidence from Community Health Workers in an Aspirational District of India

Anshuman Thakur [1], Reshmi Bhageerathy [1,*], Prasanna Mithra [2], Varalakshmi Chandra Sekaran [3] and Shuba Kumar [4]

[1] Department of Health Information Management, Manipal College of Health Professions (MCHP), Manipal Academy of Higher Education (MAHE), Manipal, Karnataka, India

[2] Department of Community Medicine, Kasturba Medical College Mangalore, Manipal Academy of Higher Education (MAHE), Mangalore, Karnataka, India

[3] Prasanna School of Public Health (PSPH), Manipal Academy of Higher Education (MAHE), Manipal, Karnataka, India

[4] Samarth, Chennai, Tamil Nadu, India

[*] Correspondence: reshmi.b@manipal.edu

Abstract

Background/Objectives: This study examines the social epidemiology of digital health adoption and the determinants of the digital divide among Community Health Workers (CHWs), including Accredited Social Health Activists (ASHAs), Anganwadi Workers (AWWs), Auxiliary Nurse Midwives (ANMs), and their supervisors in Muzaffarpur, Bihar, India's most populous aspirational district, with a focus on inequities across cadres, departments, and rural and urban contexts. **Methods:** An exploratory sequential mixed methods design was used. The quantitative phase included a cross-sectional survey of 95 CHWs across four blocks spanning urban, semi-urban, rural, and flood-prone areas. The qualitative phase comprised 32 in-depth interviews with CHWs, and block-level officers and six focus group discussions stratified by cadre and setting. Research tools were grounded in the behavior model. Quantitative data were analyzed using Jamovi software, and qualitative data with ATLAS.ti. **Results**: Urban, higher-income, and better-educated cadres reported greater use of digital applications, while limited device functionality, lower education, and rural flood-affected location constrained digital engagement. ANMs experienced app fatigue from multiple platforms, while AWWs and ASHA faced persistent device failures and financial burdens from personal smartphone use. Block-level officers and CHWs highlighted ongoing barriers, including technical failures, fragmented systems, workload, and reliance on informal support. **Conclusions**: The digital divide is shaped by intersecting social and structural factors across cadres, departments, and geography. Bridging this gap requires equitable infrastructure, continuous training, integrated user-centered systems, and supportive policy to ensure digital health reforms advance health equity in low-resource settings.

Keywords: social epidemiology; digital health; digital divide; community health workers; social determinants; aspirational districts; mixed methods; India

1. Introduction

1.1. The Global Rise of Digital Health and Persistent Digital Inequities

Digital health technologies have emerged as foundational tools for advancing Universal Health Coverage (UHC) and achieving Sustainable Development Goals (SDGs), especially Goal 3, which targets good health and well-being for all. Since the launch of the World Health Organization's (WHO) Global Strategy on Digital Health 2020–2025, digital solutions have been promoted as vital

for overcoming gaps in service delivery, health information management, and patient empowerment in both high- and low-income countries [1,2].

However, the global digital health revolution has not benefited populations equally. The "digital divide," defined as unequal access to and capacity to use digital technologies, remains a key barrier to health equity. [3,4]. Low- and middle-income countries (LMICs) are particularly affected, with pronounced disparities in digital infrastructure, device ownership, digital literacy, and internet connectivity between and within nations [5,6]. Recent estimates indicate that, as of 2024, approximately 2.6 billion people worldwide remain offline, with most of these unconnected individuals living in rural areas, particularly in South Asia and sub-Saharan Africa; of the global offline population, nearly 1.8 billion reside in rural locations [7]. Despite increasing coverage and global policy emphasis on digital solutions, substantial inequities in digital access persist, shaped by intersecting social determinants such as income, education, gender, and geography, which continue to determine who benefits from digital technologies and who remains excluded [7,8].

1.2. Social Epidemiology and the Digital Divide in Health

Social epidemiology provides a critical framework for understanding how structural factors such as socioeconomic status, gender, geography, and education interact to create digital health inequities [9,10]. The concept of "digital determinants of health" underscores that digital exclusion is shaped by social context, amplifying existing health disparities [9,11]. Evidence from high-income countries indicates that marginalized groups, including low-income individuals and rural populations, are less likely to access or effectively use digital health tools [9,11]. In these contexts, digital health initiatives that fail to account for social realities risk exacerbating rather than reducing health inequities [9,11].

1.3. Community Health Workers: The Frontline of Digital Transformation

India's digital health ambitions are deeply reliant on its frontline workforce of community health workers (CHWs), which includes Accredited Social Health Activists (ASHAs), Anganwadi Workers (AWWs), and Auxiliary Nurse Midwives (ANMs) [12–16]. Collectively, these women working with the health and integrated child development services (ICDS) department represent one of the largest CHW cadres in the world, responsible for essential services in maternal and child health, nutrition, immunization, and disease surveillance [17–19].

With the introduction of the Ayushman Bharat Digital Mission (ABDM) in 2021 and the earlier rollout of digital platforms such as the Poshan Tracker, ANM online application (ANMOL), and mSakhi, CHWs have been mandated to collect and report data using smartphones or tablets [15,20,21]. Yet, the realities of implementation have been mixed. National surveys indicate that, while smartphone ownership among CHWs is rising (up to 70–80 percent in some areas), persistent device shortages, poor network coverage, and low digital literacy remain critical barriers [22–24]. In many rural and underserved districts, CHWs are expected to use personal devices and data at their own expense and often must duplicate digital entries in paper registers due to unreliable systems [25,26].

1.4. Aspirational Districts: Targeting Equity in Digital Health

The Indian government's Aspirational Districts Programme (ADP), launched in 2018, prioritizes 112 districts with the poorest socio-economic development indicators specifically in terms of human development index (HDI) for intensive, data-driven interventions [27]. Muzaffarpur, Bihar, the setting of this study, is the most populous aspirational district and remains a critical site for addressing malnutrition, maternal and child health, and digital transformation challenges [28–30].

These districts, despite receiving focused policy attention and additional resources, continue to grapple with deep-seated digital and health inequities. Recent analyses have found that digital health programs in districts with low resource settings, such as aspirational districts, are frequently undermined by fragmented app ecosystems, lack of interoperability, insufficient training, and

absence of robust technical support [25,31,32]. For CHWs, this has translated into additional workload, psychological stress, and even out-of-pocket expenses for devices and connectivity [32,33]. These operational realities underscore the urgent need to examine the social and systemic determinants of digital health adoption at the frontline.

1.5. Theoretical Frameworks for Understanding Digital Health Adoption

To unravel the complexities of digital health adoption among CHWs, it is essential to use well-established theoretical frameworks. This study is grounded in the Health Belief Model (HBM), which focuses on individuals' perceptions of benefits, barriers, self-efficacy, and cues to action in determining behaviours [34,35]. However, it's not just limited to the HBM and draws from the technology acceptance model (TAM), theory of planned behaviour (TPB), and unified theory of acceptance and use of technology (UTAUT)[36–39]. In the digital context, these theories allow for analysis of why some CHWs accept and use new digital tools, while others struggle or resist, even within similar environments [38].

At the same time, technology acceptance models provide important complementary insights. The Technology Acceptance Model (TAM) emphasizes perceived usefulness and perceived ease of use as key predictors of adoption [40,41]. The Unified Theory of Acceptance and Use of Technology (UTAUT) integrates elements of TAM and other theories, including social influence and facilitating conditions, to predict actual use [39]. The Theory of Planned Behavior (TPB) further highlights the role of attitudes, subjective norms, and perceived behavioral control [37]. These frameworks have all informed the design of this study's survey instruments, interview, and FGD guides, and are increasingly recommended for digital health research in LMICs [33,42].

1.6. Study Rationale and Objectives

Despite ambitious digital health policies, significant gaps remain in understanding how social determinants shape the actual adoption, sustained use, and impact of digital health technologies at the frontline in India. Quantitative studies have typically focused on rates of device ownership or app use, while qualitative investigations exploring lived experiences, coping strategies, and systemic barriers among CHWs in aspirational districts are scarce.

This study seeks to fill these gaps by adopting a social epidemiological perspective, grounded in behavioral and technology acceptance theory, to examine the digital divide and its determinants among CHWs in Muzaffarpur, Bihar. The specific objectives are to:

1. Quantitatively assess the socio-demographic profile, digital access, and determinants of digital health tool use among CHWs.
2. Qualitatively explore perceived benefits, barriers, and adaptive strategies from the perspectives of CHWs and their supervisors.
3. Synthesize findings to provide actionable recommendations for more equitable and effective digital health systems in high-need Indian districts.

Through this approach, the research aims to generate contextually rich, policy-relevant evidence for India and other LMICs striving to bridge digital divides in frontline health delivery specially for the areas with poor resource availability and/or utilization.

2. Materials and Methods

2.1. Study Design

This study is part of an ongoing doctoral research project (Protocol ID: IEC1:354/2022) at the Department of Health Information Management, Manipal College of Health Professions, Manipal Academy of Higher Education, Karnataka, India. An exploratory sequential mixed-methods design was adopted to comprehensively investigate the digital health landscape among Community Health Workers (CHWs) in Muzaffarpur, Bihar. The design facilitated both quantitative baseline assessment

of digital health adoption patterns among CHWs and qualitative exploration of lived experiences and implementation challenges among CHWs and their block-level officers. The research design was grounded in leading qualitative and mixed methods frameworks, drawing especially on Maxwell (2013) for conceptual clarity in qualitative research design, while integrating principles from Creswell and Plano Clark (2018) and Fetters et al. (2013) to ensure meaningful incorporation of quantitative baseline findings. This approach facilitated a rich, contextually nuanced understanding of the social and systemic determinants of the digital divide, with qualitative narratives anchored by relevant quantitative insights [43–45].

2.2. Study Setting

The research was conducted in Muzaffarpur, the most populous Aspirational District in Bihar, characterized by persistent health inequities, infrastructural gaps, and diverse socio-economic challenges. This research setting is notable for persistent health inequities, recurring outbreaks of Acute Encephalitis Syndrome (AES) in children, and a high burden of visceral leishmaniasis [28,30]. To capture the heterogeneity of frontline digital health work, four blocks—Katra, Paroo, Musahari, and Kanti were purposively selected to represent a spectrum of flood-prone and remote rural, semi-urban, and urban environments.

2.3. Participants and Sampling

Quantitative Phase

The quantitative component targeted all three major cadres of CHWs: ASHA, ANM, and AWW. A two-stage stratified random sampling method was used. First, the four study blocks were selected to ensure diversity by geography and urbanicity. Next, within each block, CHWs were randomly drawn from official registers by random selection of health and wellness centres to select ANMs and matching ASHA and AWWs, as usually each ANM serves a population of around 5000; however, the ASHA and AWWs serve the population of 800-1000, and in resource-constrained settings, the number could double for all three cadres [14,46,47]. Sample size was calculated using a standard sample size calculator, applying a 95% confidence level, 10% margin of error, and 50% population proportion to the total CHW population of 8,291 in Muzaffarpur. This resulted in a final sample of 95, proportionately divided into 43 ASHAs, 7 ANMs, and 45 Anganwadi Workers [48].

Qualitative Phase

The qualitative phase employed purposive sampling to maximize information power [49] and capture a wide range of experiences. In each block, two in-depth interviews (IDIs) were conducted with each cadre of ASHA, AWW, and ANM, yielding a total of 24 CHW interviews. Additionally, six focus group discussions (FGDs) were organized, with two FGDs each among ASHAs, AWWs, and ANMs, stratified by rural and urban blocks to surface contextual differences. Selection criteria included cadre, years of experience, and block location. To triangulate frontline perspectives with block-level program management insights, all eight block-level supervisors (four Medical Officers In-Charge from the health department and four Child Development Project Officers from ICDS) participated in individual interviews.

2.4. Data Collection

Quantitative Data

Quantitative data for the baseline survey were collected using a structured questionnaire comprising 12 items. The survey captured socio-demographic characteristics (including name, age, gender, education, residence, and place of duty), work history (years of service), and digital health practices, such as access to personal and government-provided Android phones, the number and names of data entry applications used, and the identity of the immediate reporting officer for digital

health tasks. All data were collected face to face after filling up the informed consent form, with responses directly entered and cross-verified by the research team to ensure accuracy.

Qualitative Data

Semi-structured guides for in-depth interviews (IDIs) and focus group discussions (FGDs) were developed in English, aligned with the main study protocol and mapped to constructs from the HBM, TAM, TPB and UTAUT. These guides were subsequently translated into Hindi to ensure clarity and contextual relevance for all participants. IDIs explored individual experiences with digital health, adaptation strategies, perceived barriers, and impacts of digitalization, while FGDs focused on collective perspectives regarding implementation challenges, peer support, and the influence of social networks. Block-level supervisor interviews specifically examined governance, training, and system-level bottlenecks. All qualitative interactions were conducted in Hindi, audio-recorded with participant consent, transcribed verbatim, and then translated into English for analysis, preserving key cultural expressions and terminologies.

2.5. Data Analysis

Quantitative Analysis

Quantitative data were analyzed using Jamovi software. Descriptive statistics characterized the CHW workforce and digital infrastructure landscape.

Qualitative Analysis

Qualitative transcripts were coded using ATLAS.ti. A hybrid deductive-inductive thematic approach was applied [50], drawing initial codes from HBM, TAM, TPB, and UTAUT while allowing emergent themes from the data. Coding was performed by the first author and randomly cross-verified by three co-authors, with discrepancies resolved through discussion and consensus, leading to a refined codebook. Thematic saturation was considered achieved when no new insights emerged from the data.

2.6. Ethical Considerations

This study received ethical approval from the Institutional Ethics Committee of Kasturba Medical College and Hospital, Manipal Academy of Higher Education (Approval No.: IEC1:354/2022), and adhered to the parent PhD research protocol. Written informed consent was obtained from all participants. Administrative permissions were secured from the Muzaffarpur District Health Society and ICDS office. Confidentiality and data security were strictly maintained, with de-identified data stored on secure, access-restricted servers.

2.7. Reflexivity and Trustworthiness

The research team engaged in ongoing reflexivity, drawing on the multidisciplinary expertise of investigators in digital health, epidemiology, and qualitative research. Regular team debriefings and field notes were maintained to enhance analytic rigor and reduce bias [51]. Methodological rigor was further supported by triangulation across quantitative, qualitative, and documentary data, as well as peer debriefing with independent scholars in public health.

3. Results

This section presents the findings of the study through a social epidemiology lens, integrating quantitative survey data with extensive qualitative evidence from interviews and focus group discussions. The results move beyond a surface description of barriers and benefits to elucidate how digital health implementation acts as a mechanism of social stratification, intensifying inequities among CHWs and revealing new forms of adverse digital incorporation. These findings are

organized to highlight the multi-layered nature of the digital divide, the mirroring and reinforcement of social hierarchies by digital health initiatives, and the everyday lived realities and coping strategies of CHWs at the frontline.

3.1. Quantitative Findings: A Landscape of Stratified Access

3.1.1. Demographic and Socio-Economic Context

The baseline survey included 95 CHWs: 43 Accredited Social Health Activists (ASHAs), 45 Anganwadi Workers (AWWs), and 7 Auxiliary Nurse Midwives (ANMs), recruited from urban, semi-urban, rural, and flood-prone blocks to ensure broad contextual representation. The workforce was highly experienced, with an average age of 43.2 years and a mean service duration of 13.9 years.

Socio-economic stratification was striking. ANMs were the most highly educated, with 57.1 percent holding a graduate degree or higher, followed by AWWs (26.6 percent) and ASHAs (9.3 percent). Income disparities mirrored this hierarchy: the mean annual income was INR 88,709 overall, but by cadre was INR 373,028 for ANMs, INR 71,915 for AWWs, and INR 60,000 for ASHAs. These social determinants—education and income—directly influenced digital literacy, engagement, and ability to adapt to new health technologies.

3.1.2. Digital Access: Ownership, Functionality, and Patterns of Use

Personal smartphone ownership was high (78.9 percent overall), suggesting substantial willingness and investment by CHWs. However, only 38.9 percent had a functional government-issued smartphone, exposing a deep gap between personal adaptation and official provision. This was especially acute among AWWs, where 82.2 percent reported their government-issued phones as non-functional. For ANMs, only 14.3 percent reported using a functional government tablet; the remainder had to rely on their own or others' devices.

Patterns of digital engagement mirrored these inequalities. ANMs, who were best resourced and educated, used the most digital applications (mean 4.5), followed by AWWs (2.1) and ASHAs (1.0). Urban CHWs used more apps on average (mean 2.0) than their rural counterparts (mean 1.5), reflecting additional gradients by location and infrastructure.

Table 1. Demographic and Professional Profile of CHWs by Cadre and Area (n=95).

Variable	ASHA (n=43)	AWW (n=45)	ANM (n=7)	Rural (n=48)	Urban (n=47)	Total (n=95)
Mean Age (years)	42.9	44.2	39.3	43.1	43.4	43.2
Years in Service (mean)	11.7	16.7	10.1	14.8	13.0	13.9
Mean Annual Income (INR)	60,000	71,915	373,028	93,791	83,519	88,709
Graduate or Above (%)	9.3	26.6	57.1	12.5	29.8	21.1
≤12th Grade (%)	90.7	73.4	42.9	87.5	70.2	78.9
Apps Used (mean)	1.0	2.1	4.5	1.5	2.0	1.8

3.1.3. Education and Rural–Urban Digital Divide

Urban CHWs had a higher proportion of graduates or above (29.8%) compared to rural CHWs (12.5%). However, rural CHWs were more likely to have access to a functional government smartphone (45.8%) than urban CHWs (31.9%). The mean number of apps used for work was higher in urban CHWs (2.0) compared to rural (1.5). Among the three cadres, ANMs used a mean of 4.5 applications, AWWs used 2.1, and ASHAs used just 1.0.

Table 2. Educational Level and Digital Practice by Area.

Area	Graduate or Above (%)	≤12th Grade (%)	Mean Apps Used
Rural (n=48)	12.5	87.5	1.5
Urban (n=47)	29.8	70.2	2.0

3.1.4. Digital Access and Device Functionality

Personal smartphone ownership was reported by 78.9% of CHWs, but only 38.9% had a functional government-issued smartphone. This proportion was notably lower among urban CHWs (31.9%) compared to rural CHWs (45.8%). Nonfunctional government smartphones were prevalent, especially among AWWs (82.2%). Tablets were provided exclusively to ANMs, with just 14.3% of those being functional.

Table 3. Digital Device Ownership and Functionality Among CHWs.

Device/Access	ASHA (%)	AWW (%)	ANM (%)	Rural (%)	Urban (%)	Total (%)
Personal Smartphone	62.8	91.1	100	79.2	78.7	78.9
Functional Govt. Smartphone	69.7	15.6	0	45.8	31.9	38.9
Nonfunctional Govt. Smartphone	2.3	82.2	0	41.7	45.8	40.0
Tablet Provided	0	0	100	25.0*	0	7.4*
Functional Tablet	0	0	14.3	25.0*	0	1.1*

3.2. Qualitative Findings: The Digital Divide as a Multi-Layered Cascade

3.2.1. The First-Level Divide: Functional Access, Not Just Ownership

Device ownership was necessary, but not sufficient. Across cadres, the most critical divide was access to functional, supported tools. AWWs faced a near-total collapse of government-issued Panasonic phones, described by an urban CDPO as "Almost 90 percent of the phones have become faulty." ASHAs, where government phones were provided, found them constrained by low storage, poor performance, and restricted downloads. ANMs received tablets, but many described them as "slow, with non-responsive screens," or "no working SIM card for data."

This initial hardware failure led to a forced shift: "We somehow manage to work using other people's phones or by buying new phones ourselves," reported a rural AWW. Many urban ASHAs never received a government phone at all: "No, the government has not provided any phone yet, but I use my own phone." In flood-prone blocks like Katra, persistent network outages and a lack of electricity at Anganwadi centers further undermined digital engagement, making timely data entry nearly impossible.

3.2.2. The Second-Level Divide: Digital Skills, Literacy, and Social Capital

The hardware gap generated new inequalities in digital literacy and support. CHWs without reliable devices, prior smartphone exposure, or strong family support—especially older or less-educated women were systematically disadvantaged. The ability to navigate English-language or complex apps became a decisive factor. As an ANM explained, "If the app were in Hindi, it would be much easier for us."

Formal training was almost universally described as superficial or perfunctory: "There has never been proper training for Ashwin," said one ASHA group. In practice, a "shadow training" system

emerged, reliant on peer-to-peer learning ("two learn properly, and they help the other six") and technical assistance from family, particularly children ("My son helps me understand and fill it out"). This coping mechanism, while resourceful, further stratified advantage within CHW groups based on access to social capital.

3.2.3. The Third-Level Divide: Outcomes, Burdens, and Adverse Incorporation

The final divide manifested in cadre-specific outcomes and burdens.

For ANMs, the primary outcome was cognitive and operational overload, also called "app fatigue." ANMs toggled between up to ten non-interoperable apps each day, leading to redundant data entry, confusion, and demotivation. As one urban ANM described, "I register the same patient in three different apps—Anmol, Bhavya, and UWIN. It consumes the whole day."

For ASHAs, the burden was financial toxicity. The Ashwin Portal brought transparency to payments ("With Ashwin Portal, we now receive payments monthly… we can see directly on our phones whether the money has been credited or deducted"), but its complex procedures and lack of training led many to depend on informal facilitators, often for a fee: "BCM also did it, but they charged money too. BCM took at least two hundred rupees. Every month, they take money." This portal of empowerment became, in practice, a portal of financial vulnerability.

For AWWs, the outcome was failed inclusion, meaning they were forced to purchase and maintain personal phones to fulfill their duties due to the failure of government-provided devices. "Even if we buy a phone ourselves, spending INR 12,000 is a big amount for us," lamented an urban AWW.

Table 4. Summary of Key Qualitative Themes by Cadre and Setting.

Theme	ASHA (Rural)	ASHA (Urban)	AWW (Rural/Urban)	ANM (Rural/Urban)
Device Malfunction or Lack	High	High (None)	Universal	Moderate to High
Multiple App Burden	Low	Low	Low	High
Dual Record Keeping	High	High	High	High
Data Allowance Inadequate	High	High (None)	High	High (Irregular)
Informal Payments for Tasks	Moderate	High	Low	None
Peer or Family Support for Digital	High	High	High	Low to Moderate
Stress or Work-Family Conflict	High	High	Moderate	High

3.3. Social Epidemiology in Action: Intersectionality and Structural Reproduction

3.3.1. Professional Hierarchies and Mirrored Digital Burdens

The digital health system is mapped directly onto professional hierarchies. ANMs, the most educated and best paid, were loaded with complex clinical apps and faced the threat of salary deductions for missed digital targets. AWWs and ASHAs, on lower rungs, were exposed to more basic but less supported digital systems and greater financial exploitation. Verification of ASHA work by ANMs in the Ashwin system further reinforced power dynamics and dependence.

3.3.2. Gendered and Generational Patterns

The all-female CHW workforce encountered challenges as workers and as women. Relying on sons or younger men for help with digital tasks ("My son does it, he makes me understand") reinforced dependency and patriarchal norms. The encroachment of digital work into family time, often late at night due to network issues or workload, led to conflict and stress: "Fights do happen. They say we are on the mobile the whole day." The second shift of unpaid digital labour was both gendered and invisible, deepening the psychosocial cost of digitalization.

3.3.3. Geographic and Infrastructural Determinants

Spatial patterns compounded social determinants. In flood-prone and remote blocks like Katra, network outages and a near-total lack of electricity at Anganwadi centers produced delays, backlogs, and suspicion from supervisors. Urban CHWs, while often better connected, sometimes received no official devices at all, highlighting an inequitable and inconsistent rollout of resources. Geography thus amplified patterns of cumulative disadvantage.

3.4. The Shadow System: Informal Economies, Unpaid Labor, and Digital "Shadow Work"

A critical finding is the dependence on adverse digital incorporation, where CHWs are not merely excluded by the digital divide, but are instead harmfully included in dysfunctional systems that extract their unpaid labour, time, and resources. The state's failure to provide functional tools and training has created a vast shadow support system: peer mentors, family helpers, cyber cafe operators, and informal local troubleshooters.

ASHAs and AWWs reported pooling money to pay operators or cyber cafe staff for mass data uploads at reporting deadlines, creating a shadow economy around digital compliance. This outsourcing, invisible in official adoption metrics, both masks skill gaps and imposes additional costs on the most under-resourced workers.

Within CHW teams, new hierarchies have emerged. Those with higher digital literacy have become informal leaders, sometimes charging fees or accruing status for their support, which can generate resentment or dependency. In this way, digital transformation has reconfigured not only workflows but also social power.

3.5. Managerial Perspectives: Recognition and Reform

Block-level supervisors, including Medical Officers In-Charge (MOICs) and Child Development Project Officers (CDPOs), fully corroborated frontline experiences, noting that "Almost 90 percent of the phones have become faulty." Supervisors described the burden of institutional layering, with new apps and reporting mandates repeatedly added without retiring old systems. This over-governance often left CHWs more accountable, but less supported and increasingly disempowered.

There was a strong consensus among supervisors for urgent reform, especially the need for unified, interoperable digital platforms and systematic retraining: "If there remains one app, then there is no need to write so many." Supervisors also recognized a persistent knowing-doing gap, the disconnect between grassroots awareness of problems and higher-level policy inertia. Without structural change, digital initiatives will continue to reinforce, rather than reduce, frontline inequities.

3.6. Additional Insights: Digital Disenchantment, Motivation, and Withdrawal

While initial enthusiasm for digital health was high among many CHWs, repeated technical failures, growing complexity, and a lack of meaningful support have led to a state of digital disenchantment. Some experienced workers described gradually withdrawing, doing only the minimum digital work required, or reverting to trusted paper methods where possible. For others, repeated breakdowns eroded morale and increased skepticism toward future digital innovations, making the risks of workforce disengagement real and pressing.

At the same time, resilience and adaptability were notable. CHWs continually innovated coping strategies, from forming WhatsApp troubleshooting groups to self-learning via YouTube. However,

the fact that these mechanisms are essential to program survival highlights how much of the system's success is subsidized by the unpaid and often invisible labor of its most precarious actors.

3.7. Synthesis: The Digital Divide as Dynamic Social Stratification

This study reveals that digital health reforms in low-resource settings like Muzaffarpur have not simply failed to bridge existing social and economic divides, but, in many cases, have layered new and complex forms of disadvantage atop the old. The digital divide is not a monolithic barrier of access, but a dynamic, cascading series of inequities, starting with device provision and moving through digital literacy, social support, financial risk, and psychosocial strain. These inequities are fundamentally shaped by cadre, education, income, geography, and gender, and further stratified by evolving peer hierarchies and institutional inertia.

Despite these challenges, the resilience, innovation, and commitment of CHWs are remarkable. However, the system's reliance on unpaid and invisible forms of support represents a profound externalization of costs from the state to individual workers and their families, a critical finding for future policy, design, and implementation of digital health in India and similar low-resource settings.

4. Discussion

This mixed-methods study provides a detailed, contextually grounded examination of the digital health transition in one of India's Aspirational Districts. By systematically integrating quantitative evidence with in-depth qualitative narratives, this research uncovers the layered and interconnected social, economic, and systemic factors shaping both the adoption and the everyday lived experience of digital health tools among CHWs and their supervisors. The findings must be interpreted within both national and international contexts to fully appreciate their implications for the future of digital health, social epidemiology, and UHC in LMICs

4.1. Digital Inequities and the Social Epidemiology of Technology

This study reinforces the critical understanding that digital divides in health are not isolated or technological in origin but are deeply interwoven with existing social, economic, and gendered inequities [8,9]. The data demonstrate that ANMs, as salaried employees, benefit from higher educational attainment and income, mirroring findings across LMICs that digital access and literacy are closely shaped by cadre, professional status, and financial security [52,53]. While urban CHWs tend to have higher levels of education, rural CHWs paradoxically report better access to functional government-issued smartphones, likely reflecting local distribution policies and the role of block-level support in device allocation [54,55].

High rates of personal smartphone ownership among CHWs conceal a troubling reality: digital engagement is largely subsidized by the workers themselves, with direct costs for devices, data, and repairs falling on those with the lowest, often incentive-based, incomes [56,57]. This aligns with emerging literature on "adverse digital incorporation" [3], where CHWs are included in digital systems under conditions that reinforce rather than alleviate financial precarity. The gendered dimension is acute; female CHWs often require help from male relatives to navigate complex platforms and face additional barriers from patriarchal norms and language limitations [58,59]. Unless addressed, digital health programs risk reinforcing the very dependencies and inequities they seek to reduce [60].

These findings support a growing consensus that digital determinants of health should be recognized as central to both the effectiveness and equity of health interventions [8,61].

4.2. The Paradox of Digital Empowerment and New Vulnerabilities

The qualitative phase of this study exposes a deep paradox: digital tools can empower CHWs, streamlining reporting and improving transparency (e.g., timely incentive payments through platforms like Ashwin), yet, for most, digitalization has introduced new vulnerabilities. Dual data

entry remains common; CHWs are required to maintain paper records alongside digital apps, doubling the administrative burden and perpetuating inefficiency [62–64]. The proliferation of non-integrated applications further compounds confusion and increases errors, with a lack of system interoperability recognized as a major source of inefficiency and dissatisfaction in both national and global policy documents [2,32,64–66].

The direct and indirect costs of digital participation, including paying for data, repairs, and sometimes informal technical support, drive CHWs to seek assistance from peers or family, occasionally through informal payments [56,67]. Such arrangements erode the efficiency and intended equity of digital platforms, introducing new opportunities for exploitation. Beyond financial and operational burdens, the emotional and psychological toll is substantial, especially for women balancing household and professional duties, often exacerbated by night-time data entry and technical failures [25,58,59,68,69].

4.3. Systemic Barriers and the Implementation Gap

Barriers to effective digital health implementation are cumulative and interconnected. Poor quality devices, unreliable network connectivity, and insufficient, one-off training programs repeatedly surfaced as key challenges (Gudi et al., 2021; Scott et al., 2022; Pal et al., 2017). The persistence of paper records, increased risk of data loss, and an erosion of trust in digital systems are further manifestations of these systemic gaps. Notably, informal peer and family networks have become essential for bridging digital literacy gaps, but their reach and sustainability remain limited—placing the greatest burden on the least literate, older, or more socially isolated CHWs (Kadhuluri et al., 2023; Rashmi Kundapur et al., 2022; Werfalli et al., 2020).

A critical structural barrier is the absence of robust, ongoing, and context-specific digital training. Most existing programs are formalistic, episodic, and do not provide the practical, iterative support that is essential for sustained digital competency (Majhi et al., 2021; Olaniran et al., 2022; Woods et al., 2024).

4.4. The Case for Integration and User-Centric Reform

There is a universal demand among CHWs and supervisors for an integrated, interoperable digital health system. The proliferation of unconnected apps, each with separate reporting and data entry requirements, is a principal source of dissatisfaction and inefficiency. National (ABDM) and global (WHO, 2021) guidelines now consistently highlight interoperability as a foundational requirement for sustainable digital transformation (Labrique et al., 2018; Kouroubali & Katehakis, 2019; Holeman et al., 2024).

Participatory, user-centric approaches—where CHWs co-design platforms, interfaces are simplified, and language and gender realities are prioritized—are associated with greater adoption, efficiency, and satisfaction (Ismail & Kumar, 2019; Juste et al., 2021; Holeman et al., 2024). Such reforms are crucial to moving beyond fragmented pilot projects to achieve scalable, sustainable impact.

4.5. Broader Context: National and Global Resonance

The challenges seen in Muzaffarpur echo those across India and other LMICs: fragmented digital ecosystems, infrastructural deficits, lack of training, and entrenched inequities [1,2,70]. Resource-constrained settings, such as aspirational districts, in particular, face the compounded effects of social disadvantage and weak system integration [71–73]. International research and global guidelines reinforce the need for participatory, context-sensitive, and gender-responsive approaches to digital health implementation, especially among marginalized populations [2,74–79].

4.6. Policy Implications and Future Directions

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Urgent public investment is required in high-quality, universally accessible digital infrastructure and robust technical support for all CHWs. Policy must move beyond the provision of software or incentive payments to cover the "total cost of ownership," including devices, connectivity, maintenance, and recurrent training [3,57]. Integration of digital platforms should be a priority, eliminating redundancy and cognitive burden, and aligning with the objectives of India's ABDM and WHO's best practices [2,20].

Training models should be continuous, peer-led, and practical, leveraging informal networks but formalizing and supporting them through recognition and incentives [80,81]. User-centric design sensitive to language, literacy, and gendered experiences is essential for equitable digital empowerment [38,82]. The persistence of informal payment systems must be tackled through transparency, support, and governance reforms to protect workers and ensure data quality [83,84].

4.7. Strengths and Limitations

The principal strength of this study is its mixed-methods design, integrating statistical and thematic data to provide a holistic understanding of digital transition at the community level in a high-priority, under-researched setting. Limitations include the restricted geographic focus, self-reporting bias, and lack of longitudinal follow-up; however, the resonance of these findings with national and global literature underscores their wider relevance.

5. Conclusions

This research demonstrates that the digital health transition among Community Health Workers in an Aspirational District of India is fundamentally shaped by entrenched structural, social, and gendered inequities. Despite government-led efforts to digitize primary health care, adoption and impact remain uneven, most notably among lower-paid, less-educated, and rural or female workers. CHWs exhibit extraordinary resilience but are too often compelled to use personal resources to compensate for gaps in devices, platforms, training, and connectivity, thereby reinforcing pre-existing disparities. While digital tools are seen as beneficial for transparency and efficiency, they frequently add to the workload, financial burden, and emotional strain, necessitating reliance on informal support networks. The urgent need for unified, interoperable systems and robust support is evident. Addressing the digital divide in health requires policy attention to the full spectrum of digital determinants, comprehensive infrastructure investment, participatory design, elimination of informal payments, and above all, a centering of the experiences and needs of frontline workers. Without such reforms, digital health initiatives risk perpetuating or deepening health disparities in low-resource settings. Only by empowering CHWs as both agents and beneficiaries of digital health can the promise of equity, empowerment, and UHC be realized.

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Abbreviations

The following abbreviations are used in this manuscript:

Abbreviation	Full Term
ABDM	Ayushman Bharat Digital Mission
AI	Artificial Intelligence
ANM	Auxiliary Nurse Midwife
ANMOL	Auxiliary Nurse Midwife Online
APA	American Psychological Association
ASHA	Accredited Social Health Activist
AWW	Anganwadi Worker
BCM	Block Community Mobilizer
Bhavya	Government digital health application
CDPO	Child Development Project Officer
CHC	Community Health Centre
CHW	Community Health Worker
COVID-19	Coronavirus Disease 2019
DPHO	District Public Health Officer
FGD	Focus Group Discussion
HBM	Health Belief Model
ICDS	Integrated Child Development Services
IDI	In-Depth Interview
INR	Indian Rupee
IRB	Institutional Review Board
ITU	International Telecommunication Union
LMICs	Low- and Middle-Income Countries
MAHE	Manipal Academy of Higher Education
MOIC	Medical Officer In-Charge
mSakhi	Mobile-based application for CHWs
NGO	Non-Governmental Organization
PHC	Primary Health Centre
POSHAN	Prime Minister's Overarching Scheme for Holistic Nourishment
SD	Standard Deviation
SDG	Sustainable Development Goal
TAM	Technology Acceptance Model
TPB	Theory of Planned Behavior
UHC	Universal Health Coverage
UTAUT	Unified Theory of Acceptance and Use of Technology
UWIN	Unique Identification for Immunization
VHSND	Village Health, Sanitation, and Nutrition Day
WHO	World Health Organization

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