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Preventing vaccine drop-outs: Geographic and system-level barriers to full immunization coverage among children in Uttar Pradesh, India

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ABSTRACT

Objective: Global interventions on routine immunization aim to achieve at least 90 % immunization coverage of all vaccines as per national immunization schedules, aligning with the Immunization Agenda 2030. Despite significant global progress, regions like Uttar Pradesh (UP), India's most populous state, require more efforts to meet this target.

Methods: In 2021, a quantitative survey was conducted with 10,591 mothers/caregivers of children aged 0–15 months and 479 linked community health workers (Accredited Social Health Activists, ASHAs) responsible for connecting these families with vaccine services across 444 rural villages in UP. We developed a coverage cascade to assess the coverage of all basic vaccines (1 dose of each BCG and MR, and 3 doses each of DPT/Penta and Polio), immunization dropouts, and their drivers.

Findings: While 96.4 % of service platforms had the required vaccines available and 94.7 % of children aged 12–15 months had received the first dose of Pentavalent vaccine, only 67.8 % of children received all basic vaccines, with 53.5 % completing these vaccines in the first year of life. More than half (53 %) of dropouts were concentrated in 30 % of ASHA areas. Among these areas, 13 % had no dropouts, and 29 % had more than 60 % of children aged 12–15 months with incomplete immunization. Areas with high dropout rates had higher rates of home deliveries, lower possession of parent-held vaccination records (MCP cards), and poor community-level factors such as incomplete record keeping by ASHAs, less supportive supervision by their supervisors, and relatively lower work motivation compared to areas with no dropouts.

Conclusion: The wide heterogeneity in immunization coverage and dropouts emphasize the need to identify area-specific patterns and reasons for low immunization coverage and to develop interventions to address them. Robust support systems for community health workers and comprehensive record-keeping are pivotal to improve immunization coverage and to reduce the burden of vaccine-preventable diseases.

1. Background

Immunization is a global health and development success story, saving millions of lives annually. Childhood vaccinations against vaccine-preventable diseases are one of the most cost-effective ways to reduce childhood mortality and morbidity worldwide [1,2]. Currently, childhood vaccination prevents 3.55 million global deaths annually from diseases like diphtheria, tetanus, pertussis, influenza, and measles [3]. However, in 2022, nearly 23 million one year old children did not receive these basic vaccines [4]. In India, despite progress, infectious diseases remain a significant cause of child mortality and morbidity. Uttar Pradesh (UP), the most populous state in north India with approximately 239 million people [5], has an annual birth cohort of about 5.7 million. Coverage of all basic vaccines (Bacille Calmette-

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Guerin (BCG), Measles and Rubella (MR), and three doses each of Diphtheria-Tetanus-Pertussis/Pentavalent (DPT/Penta) and Polio, excluding the zero/birth dose) increased from 51.1 % to 69.6 % during 2015–2021 [6]. This means about 30 % of children aged 12–23 months still did not receive all basic vaccines.

India launched the Expanded Programme on Immunization in 1978 and renamed it the Universal Immunization Programme (UIP) in 1985. UIP targets close to 26.7 million newborns and 29 million pregnant women annually, providing vaccines for 12 preventable diseases free of cost [7]. It is one of the most cost-effective public health interventions [8] and its universality aligns with the Immunization Agenda 2030 [9]. The country was certified polio-free in 2014 and eliminated maternal and neonatal tetanus in 2016 [10]. However, immunization coverage is not optimal with ongoing measles outbreaks despite over three decades of universal infant vaccination [11]. To ensure over 90 % coverage of all basic vaccines by 2018, India launched multiple rounds of focused campaigns in the form of *Mission Indradhanush (MI)/ Intensified Mission Indradhanush* (IMI), focusing on immunising hard-to-reach and tribal populations, with special sub-district level attention in UP and Bihar [12]. Despite these efforts, only 81 % of children in UP receive three doses of the Pentavalent vaccine, and timely or age-appropriate vaccination rates remain low [6].

Programmatically, it is crucial to understand the context-specific reasons for low immunization coverage and the factors associated with non-vaccination. Studies from India have primarily focused on analysing full immunization coverage (FIC) and its' determinants at individual-level such as sex of the child [13–18], maternal age [13,15,18–20], mothers' education [13–15,19–24], birth order of the child [13,15,19,23,24], child's place of delivery [15,17–19,21–23], mother's employment status [13,15,19], having a Mother and Child Protection (MCP) card (parent-held vaccination record) [14,18,25], mother's knowledge of vaccines [21,22], her agency for decision-making [15,17,26,27], caste [14,16], religion [14–16,19], and wealth quintile [13–16,18,19,21,24,25] along with a few community-level variables like community education [13,19], community wealth [19], or other contextual factors [28]. Studies have also tried to understand immunization coverage through socio-economic and geographic inequality lens [29–33], while a few also assessed the impact of interventions on immunization coverage [34,35]. However, only a few have either documented the immunization service readiness and its' linkage with the coverage [36] or reasons for non-immunization [37,38]. Since the immunization coverage is improving over the years, it is really important to understand the population that is left behind and what are the reasons for the same? To systematically understand this, we developed a coverage cascade to identify the coverage gaps/drops and the reasons contributing to these gaps. This allows to measure whether the coverage gap is due to unavailability of service, poor contact between the health service delivery platforms and the beneficiary, or primarily driven by different individual related issues such as knowledge, accesses, community and/or inter-generational practices or something else. Such coverage cascades are also used as a metric to monitor universal health coverage, measure the reproductive, maternal, newborn, and child health system performance, and determine where the most prominent gaps exist to prioritize and plan relevant interventions, usually called effective coverage cascade [39–41].

To understand the reasons for immunization coverage gaps, we used survey data collected from mothers/caregivers of children aged 0–15 months and from community-level health workers, specifically Accredited Social Health Activists (ASHAs), in less developed blocks, referred to as aspirational blocks, of UP. Our objective was to examine the full spectrum of immunization coverage by analysing the levels of coverage drop, and the geographic and demographic determinants of immunization disparities. Research findings can provide actionable insights to help planners and policymakers strengthen immunization services and address systemic barriers.

2. Methods

2.1. Data source and study setting

This study utilized data from a cross-sectional quantitative survey conducted between 27 July-30 November 2021 to estimate full immunization coverage and to identify program areas with high dropout rates. The study adopted a cross-sectional design where retrospective information was captured to assess the vaccine uptake among children aged 0–15 months and to identify factors contributing to dropout rates in UP, India. The study specifically focused on 100 administrative subdivisions, known locally as blocks, with an average population of about 0.25 million, identified based on lower performance metrics (health, education, and development) compared to national and international benchmarks.

The study was designed and conducted by the University of Manitoba (UM) and the India Health Action Trust (IHAT), an Indian non-profit organization. This collaboration provides techno-managerial support to the Government of UP to enhance maternal, neonatal, and child health outcomes, which also includes targeted interventions to attain a minimum of 90 % full immunization coverage in the intervention geographies. The study was part of the initial baseline assessment of this intervention to understand the coverage gaps and design interventions to improve them.

2.2. Participants

The survey was conducted with mothers/caregivers to assess their children's vaccination status and the date each vaccine was administered, both through the parent-held vaccine record followed by mother/caregiver's recall. Additional questions included the immunization service accessibility, adherence to immunization schedules, and reasons for any dropouts. The survey with community health workers (ASHAs) asked them about the specific barriers and challenges they faced in connecting families with immunization services. Diverging from the standard month age group commonly used in childhood immunization surveys, this study focused on children aged 0–15 months to provide a timely assessment of recent immunization efforts. This approach was based on the Indian National Family Health Survey data, which indicated that approximately 95 % of children receive the first dose of the Measles Containing Vaccine (MCV) by 15 months of age, with the MCV being the last vaccine at 9 months. Given that MCV-1 is a critical marker of the prescribed immunization schedule for full immunization [42], the study included mothers/caregivers of children within this age range.

2.3. Sample size and sampling design

The sample size for this study was determined to measure the change in immunization coverage at cluster or project level using the current level of immunization at 95 % confidence level, 80 % power, and a design effect of 2. For the current level of immunization, data on the average coverage of all basic vaccines of the 100 blocks from the Health Management Information System Data for the financial year 2019–20 was used. This resulted in a required sample size of 11,104 children aged 0–15 months for the study, to be distributed across 444 rural primary sampling units (PSU) with an estimation of about 25 children of 0–15 months per PSU of 1000 population. However, during the study, an additional 35 linked PSUs were included to fill the shortfall of the required sample size. Thus, the survey covered 479 PSUs and enumerated 11,699 eligible children aged 0–15 months for the survey. The mothers/caregivers of 10,591 children were interviewed, while data on the remaining 1108 could not be collected due to different reasons such as unavailability of the participants (1080), refusal (16); interview postponed (1); partially completed (8); participant incapacitated (1) or others (2). For the analysis of coverage of all basic vaccines, 2496 children aged 12–15 months were used (Annexure Fig. 1).

The study adopted two-staged stratified sampling to select the Primary Sampling Units (PSUs). Since blocks were organized into four programmatic clusters based on geographic contiguity for the intervention, for the sampling purpose also, first, the blocks were arranged within the clusters according to the level of immunization. Then the required number of PSUs (which were ASHA areas in this study) within each block were selected randomly within the block. This approach allowed us to provide the estimates at the program cluster level as well. The ASHA catchment areas, which are the smallest health service delivery units, each serving approximately 1000 individuals, served as the PSUs for the study. This helped in ensuring a clear demarcation of service delivery coverage point as well as interviews with ASHA to understand the service delivery mechanism pertaining to immunization. At the second stage, all children aged 0–15 months within the selected ASHA areas were enumerated and their mothers/caregivers were invited to participate in the study.

2.4. Measures

The primary outcome variable for the study was children aged 12–15 months who received all basic vaccines. Mothers/caregivers were asked about each child's vaccination status; responses of "Yes" were confirmed either by the MCP card or mother/caregiver recall, while "No" included responses indicating the child was either not vaccinated or the caregiver did not know or remember. The receipt of all doses of basic vaccines protecting against eight diseases as required by the national immunization schedule: one dose of the Bacille Calmette-Guérin (BCG) vaccine for tuberculosis, three doses of the pentavalent vaccine, covering Diphtheria, Pertussis, Tetanus, Hepatitis B, and *Haemophilus influenzae* type b (Penta-1,2,3), three doses of polio vaccine, excluding the dose given at birth (OPV-1,2,3), and one dose of measles and rubella vaccine (MR). Children not meeting these criteria were classified as not fully immunized or did not receive all basic vaccines [43]. The outcome variable was coded as "1" for children who received all eight basic vaccines and "0" for those who did not, based on the reporting in the MCP card or mothers' recall. The secondary outcomes were service readiness and quality. Service readiness was defined as children 12–15 months visiting a facility where those vaccines were available for which they visited, and access was defined as children receiving the first dose of the Penta vaccine. Quality immunization coverage was analyzed in terms of coverage of Penta3, MR1 and all basic vaccines with a focus on completion of basic vaccination by the age of 12 months.

A comprehensive set of community and individual-level variables were used to assess the multifaceted influences on full immunization coverage. At the community level, variables selected for the analysis aimed to assess the systemic and environmental factors impacting full immunization coverage, which were uniquely captured in this study. This included front-line workers' work motivation (present or lacking), and their use of resources through the completeness of the ASHA diary, or Village Health Index Register (entries noted as completed or not completed). Work motivation was assessed by asking "what are the difficulties that you faced while performing your job?" and if reported lack of motivation as one of the reason for this question (no or yes). This documentation is pivotal to maintain an organized record of healthcare activities within the community. ASHAs were asked if they received supervisory support in the last 30 days and if they had ever experienced verbal threats or intimidation in the workplace (no or yes). Environmental factors included the front-line worker's population coverage within their area (≤1000, 1000–1500, or 1500+) and if they live within the catchment area. At the individual level, demographic factors included the child's sex (boy or girl), birth order (first, second, third, or fourth), and the mother's age (<24, 24–30, or 30+ years). Socioeconomic factors were considered, including mother's education (no education, less than secondary, secondary or more), caste (Scheduled Caste/Scheduled Tribe, Other Backward Caste, or others), religion (Hindu or non-Hindu), household wealth divided into tertiles (poor, middle, or rich), and type of family structure where joint family represents a large unit including parents, children, and extended family living cohabiting, and nuclear family is a smaller unit consisting of parents and children who are more independent from extended kinship networks. Interactions with health services were measured by whether the mother had contact with an ASHA in the past 12 months, if she possessed a MCP card, and where she gave birth to the child (home or facility). The decision-making autonomy and mobility of the mother provide insight into the mother's agency and her capacity to access health services. They were quantitatively assessed using principal component analysis (PCA). Decision-making autonomy was calculated as low, medium, or high from responses concerning who primarily makes key household decisions, including financial expenditures, household purchases, women's employment status, family visits, personal healthcare, and the child vaccination and vaccination site. Mothers' mobility was calculated as low, medium, or high based on her ability to travel independently within or outside her community to places, such as markets, health facilities, and community programs.

Additionally, reasons for not getting the vaccine were demand factors, including the lack of awareness about the necessity of immunization, knowledge regarding the immunization schedules, and awareness of missed doses, mobilization issues (caregivers were not contacted by ASHAs) as well as supply constraints encompassing long waiting time, unavailable vaccines or cancelled immunization sessions, lack of information by providers about due dates for next dose, and providers not administering multiple vaccines in one session. Individual barriers, which are personal challenges by mothers/caregivers regarding availability to attend immunization sessions, work-related constraints, resistance or opposition within the family, the child being away from home, and concerns about adverse events following immunization, including experiences of minor or severe illnesses following immunization, and if the fear related to adverse events stems from direct experience, hearsay, or media reports were included.

2.5. Statistical analysis

We used descriptive methods to develop a coverage cascade [41,44], which organizes the components leading to all basic vaccination in a stepwise fashion. We quantified each stage of the immunization process, starting from the target population, comprising of all children 12–15 months. The subsequent stage is service contact coverage, calculated as the proportion of children 12–15 months accessing healthcare. Next are service readiness and access, measured as the proportion of children visiting a health facility equipped with the required vaccines. Quality was quantified at several levels: 1) the proportion of children 12–15 months old who received three doses of the Penta vaccine, 2) those who received at least one dose of the MR vaccine, 3) 12–15 months old children who received all basic vaccines, and 4) those who received all basic vaccines within the first year of life [45]. Each stage in the cascade is conditional on the preceding stage, creating a comprehensive model of vaccine delivery efficacy. Additional cascades were calculated to delineate differences in the steps leading to vaccination coverage across demographic segments, including the mother's education level, household wealth, and the child's birth order, allowing for the identification of specific drop-off points where coverage declined.

Geographic clustering of distribution of children living in blocks with varying dropout rates (none, < 60 %, and ≥ 60 %) to identify spatial patterns and areas with significant coverage gaps was presented through a map. We descriptively analyzed reasons for immunization dropout and compared these reasons across blocks with different dropout rates to ascertain whether the barriers are demand-driven, supply-related, or due to mobilization challenges. The analysis primarily focused on examining the broader socio-economic characteristics at the community level rather than only individual factors associated with dropouts. Specifically, it assessed two important aspects, first, the extent to which ASHA areas with no dropout have better socio-economic characteristics compared to those with dropouts, and second, whether children from lower socio-economic status households within any given ASHA area are more likely to experience higher dropout rates, regardless of the overall performance of the ASHA area. Differences in specific individual, household, and community-level characteristics between ASHA areas with and without vaccine dropouts have been assessed using tests on the equality of proportions from two samples and provide a foundation for targeted interventions. The analysis did not suffer with the issue of missing values in the data set. We observed three missing cases in wealth, two cases each in caste, religion, and type of household and treated them as missing values for the respective variables. Appropriate sampling weights were used in the analysis.

2.6. Ethics approval and consent to participate

The study received ethics approval from the Institutional Review Board of Sigma Research and Consulting Pvt. Ltd., New Delhi, India (10,013/IRB/21–22) and the University of Manitoba's Health Research Ethics Board (HS24847 (H2021:172)). Participants were informed about the purpose and procedure of the survey, and confidentiality was assured. Participants were free to refuse to answer any questions or withdraw at any point during the survey. Verbal informed consent was obtained from all participants, and the survey was conducted in the local language (Hindi).

3. Results

Table A1 presents the sample distribution of the 2496 mothers/ caregivers of children aged 12–15 months and adjusted percentage of children aged 12–15 months who received all the basic doses of vaccination by the individual, household, and community-level factors in the study area.

Fig. 1 depicts the coverage cascade of all basic vaccines. Of the eligible children 12–15 months expected to receive immunization, almost all (99.5 %) accessed healthcare services and 96.4 % accessed services where vaccines were available. While uptake of the first dose of Penta was nearly universal at 94.7 %, coverage of the required three doses of Penta dropped to 84.6 %. Vaccination coverage dropped to 67.8 % and only half of all children received all basic vaccines within one year of age (53.6 %). The analysis reported the highest coverage drop of 28.6 percentage points between service readiness and coverage of all basic vaccinations followed by a drop of 14.2 percentage points between coverage of all basic vaccination to timely vaccination within 12 months of age.

The stratified analysis of the coverage cascade for all basic vaccines is depicted in Fig. 2. Service contact coverage did not differ by education, wealth, and birth order. All stages of the cascade had comparable proportions and followed the same pattern between first-born children, those with educated mothers, and those with mothers who were not poor. Vaccine dropout rates were higher among second or higher birth order children and those with uneducated or poor mothers. The biggest drop and the largest difference in rates were among children of uneducated mothers, with 58.4 % being fully immunized by 15 months and 43.9 % by 12 months (compared to 73.6 % and 59.3 %, respectively among children to educated mothers).

The analysis revealed wide geographic variations in immunization dropout rates (Table 1 and Fig. 3). The transition from accessing fully equipped health services to receiving all basic vaccines saw a drop of 15.2 % in many blocks (n = 35, 35.0 %), while close to one-third of blocks (n = 36, 36.0 %) accounted for nearly half of all dropout cases (50.5 %). These blocks also represented one-third of the total ASHA areas (n = 151, 33 %) included in the study, with at least one child aged 12–15 month identified. Interestingly, not all the 151 ASHA areas had dropout children.

Table 1 shows that 13 % of ASHA areas in the high dropout blocks had no dropout children, while about 58 % of ASHA areas contributed to up to 60 % of all dropout cases. The remaining 29 % of ASHA areas included more than 60 % of children aged 12–15 months who did not receive all basic vaccines. The blocks with different levels of vaccine dropout were geographically dispersed throughout UP, with some clustering of high dropout blocks in Western UP. Despite these geographic differences, mothers in these blocks reported similar reasons

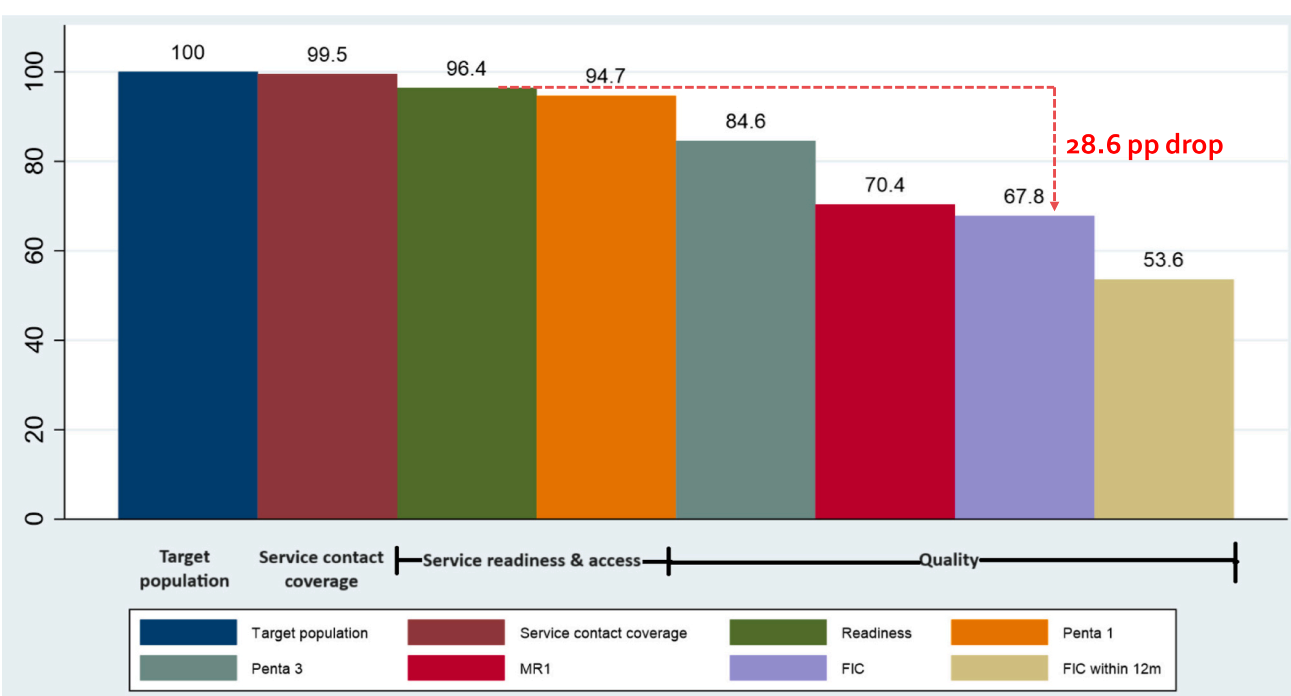

Fig. 1. Effective coverage cascade for coverage of all basic vaccines among children aged 12–15 months in Uttar Pradesh, 2021.

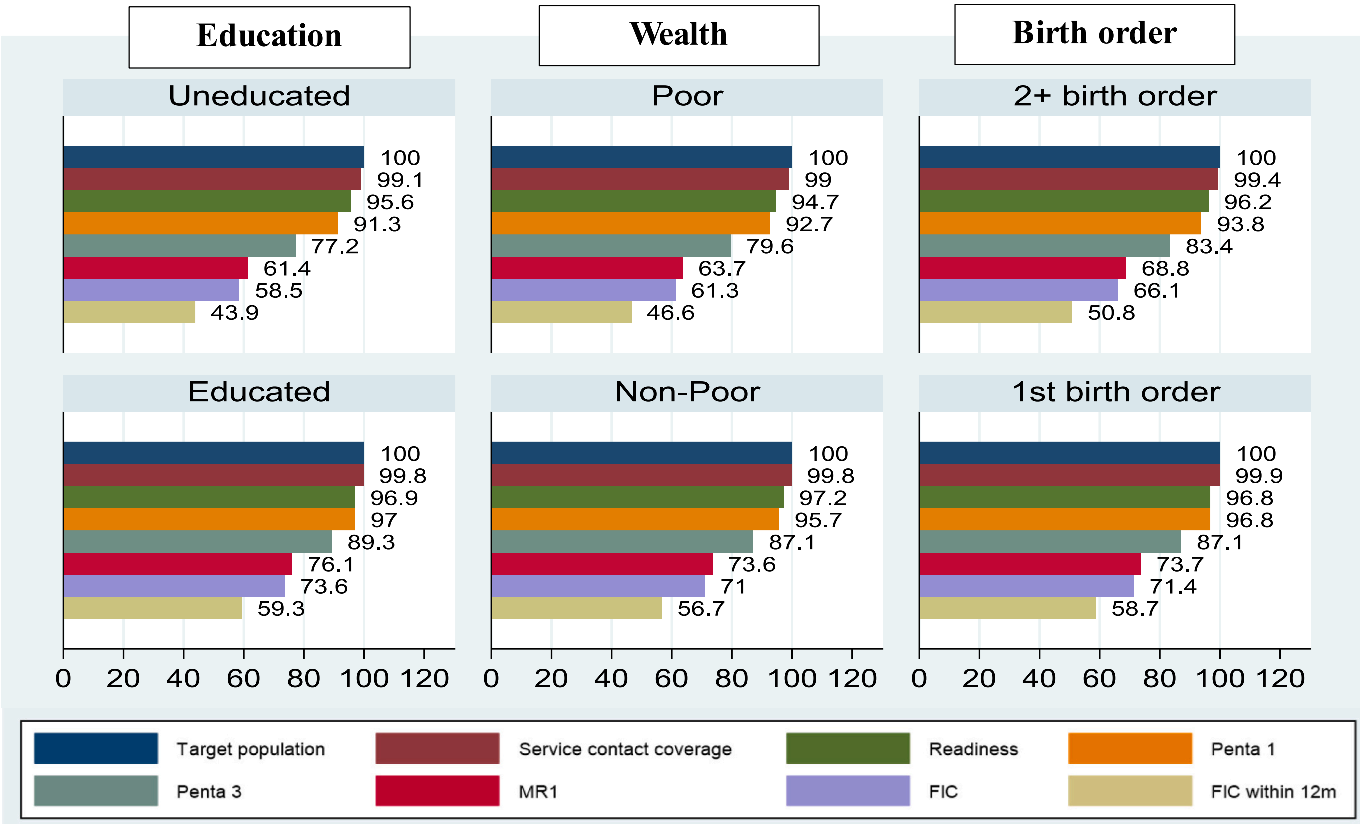

Fig. 2. Differentials in effective coverage cascade for coverage of all basic vaccines among children aged 12–15 months by socio-economic characteristics of mothers, Uttar Pradesh, 2021.

Table 1
Differentials in dropouts (coverage gaps) by group of blocks, Uttar Pradesh, 2021.

Block tertile based on % of dropouts	# of blocks (n)	# of AHSA areas (%)	Total # of children (n)	Overall dropouts* (%)	Dropout children** (% of total dropouts)	ASHA areas by dropout rate (%)		
						None	<60 %	≥60 %
Low dropout tertile	35	162 (35.4 %)	834	15.2	127 (5.1)	53.7	41.9	4.3
Medium dropout tertile	29	144 (31.5 %)	810	30.7	249 (10.0)	21.5	63.9	14.6
High dropout tertile	36	141 (33.1 %)	852	50.5	430 (17.2)	13.3	57.6	29.1
Total	**100**	**457**	**2496**	**32.3**	**806 (32.3)**	**30.2**	**54.1**	**15.8**

* Overall dropouts represent the overall proportion of children who dropped out of the vaccine schedule in the entire population within that tertile.
** Dropout children represent the proportion of children in each tertile who dropped out of the vaccine schedule relative to the total number of children in the study.

for immunization dropouts (Fig. 4). Not having been contacted was consistently the most frequently cited reason, reported by approximately 20 % of respondents. Relatively more children dropped out of the immunization schedule due to their parents' lack of awareness about the need to vaccinate in low dropout compared to moderate or high dropout blocks (16.0 %, 7.6 %, and 7.3 %, respectively).

Compared to ASHA areas where children reside who had immunization dropouts, in the ASHA areas with no dropouts, mothers were more educated (27.2 % with no education compared to 42.2 % in ASHA areas with dropouts) and lived in wealthier households (41.7 % from the highest wealth tertile versus 29.1 % in ASHA areas with dropouts) (Table 2).

Mothers living in areas without immunization dropouts were also more likely to have had an institutional birth (89.6 % versus 80.7 % in ASHA areas with dropouts), met with her ASHA in the last 12 months preceding the survey (93.0 % versus 80.7 % in ASHA areas with dropouts), and had an MCP card that contains details on whether the children received vaccines (96.2 % versus 84.3 % in ASHA areas with dropouts). Similarly, a significantly higher proportion of mothers from the areas without dropouts were residing in a joint family structure (56.0 % compared to 47.4 % in ASHA areas with dropouts), where extended family cohabits and shares resources and responsibilities and from wealthier families (41.7 % versus 29.1 % in ASHA areas with dropouts). While less than 5 % of ASHAs in all areas did not have an ASHA diary to keep track of the families in their care, ASHAs from areas with no vaccine dropouts were significantly more likely to have complete ASHA diaries to keep a record of vaccinated and dropout children than ASHAs from areas with dropouts (67.4 % and 48.9 % respectively), and were slightly more supported from their supervisors (88.3 % versus 81.6 %).

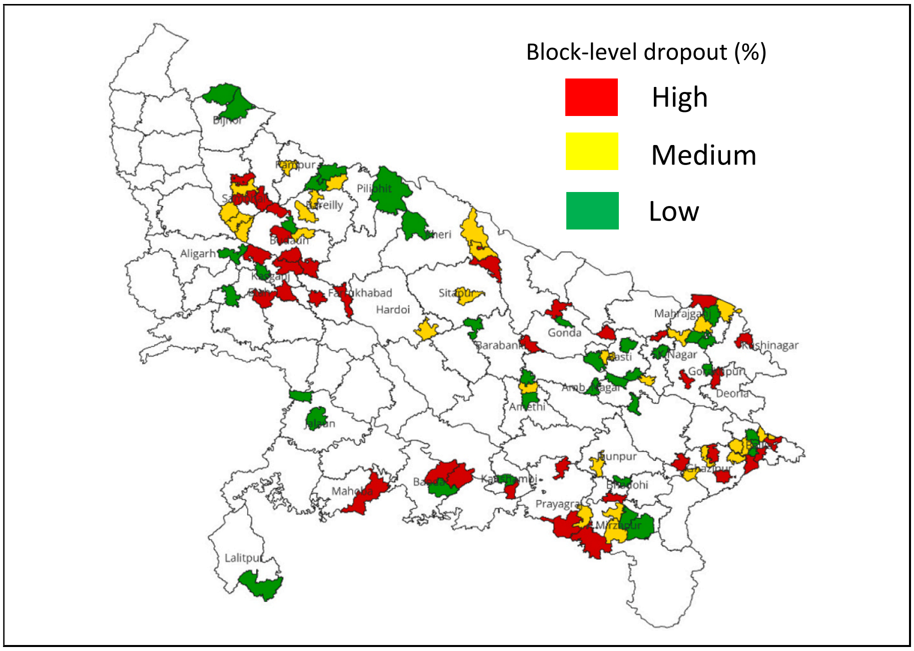

Fig. 3. Block-level geographic distribution of children with different levels of dropouts, Uttar Pradesh, 2021.

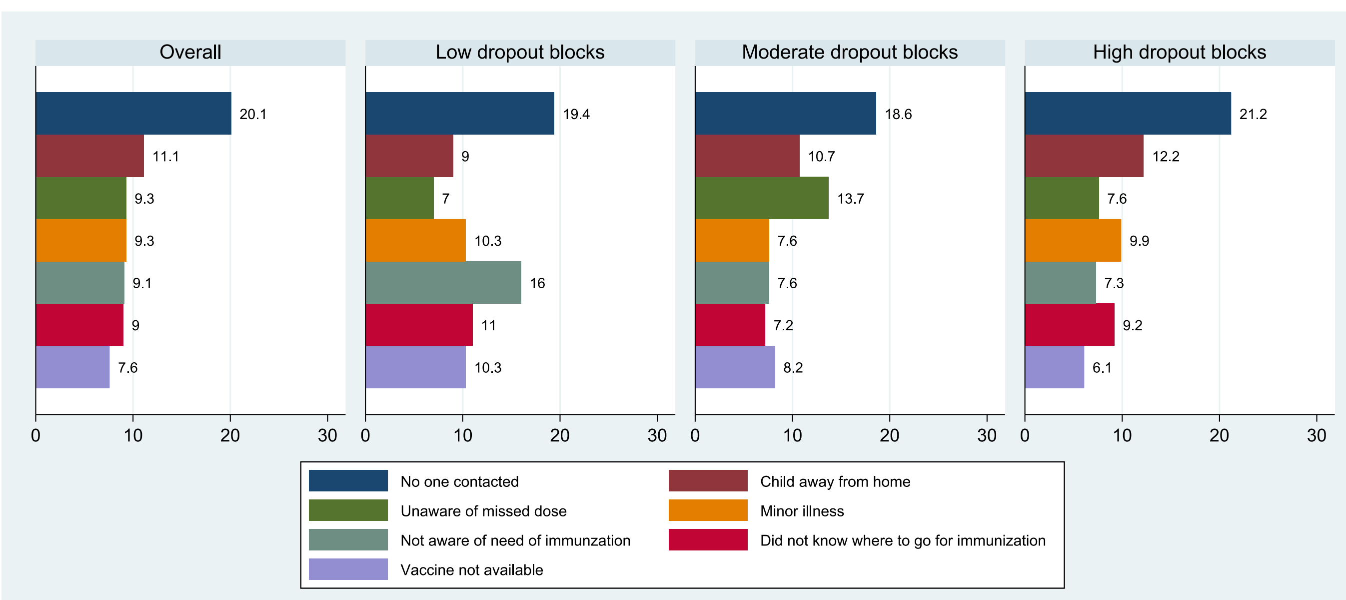

Fig. 4. Percentage of children by main reported reasons for dropout across blocks with different levels of dropouts, Uttar Pradesh, 2021.

4. Discussion

Using data from a large-scale quantitative survey, this study developed a coverage cascade to estimate both crude coverage and all basic vaccine coverage and identified the point in the cascade where the largest number of children dropped out. The comprehensive assessment of immunization coverage is critical for maximizing the protective benefits of vaccines and reducing the burden of vaccine-preventable diseases. This study pinpointed that within the immunization cascade, the greatest losses occurred between service readiness and coverage of all eight basic vaccines (28.6 percentage point drop), providing critical insights into where health interventions are most needed.

4.1. Immunization mobilization and record-keeping

We found that children who reside in the areas where ASHAs maintained complete records in their health diary/VHIR were more likely to be fully immunized compared to those in areas with incomplete records. Effective record-keeping enables ASHAs to mobilize families for vaccination on time. ASHAs play a pivotal role in educating mothers and caregivers about the importance of immunization, addressing possible misconceptions, and providing timely reminders for vaccination appointments, all of which contribute to reducing dropout rates [46,47]. Moreover, the results indicated that more than half of the children who dropped out did so due to their parent's lack of knowledge about vaccination schedules or because they were not contacted, highlighting

Table 2
Differences in individual, household and community-level characteristics of ASHA areas with any dropout and no dropout, Uttar Pradesh, 2021.

Variables	ASHA areas with any dropout		ASHA areas with no dropout		Proportion test (*p*-value)
A. Individual characteristics	**N**	**Percentage**	**N**	**Percentage**	
Mother's education					
No Education	829	42.2	144	27.2	**0.001**
<Secondary	520	26.4	165	31.1	0.239
≥ Secondary	617	31.4	221	41.7	**0.006**
Place of delivery					
Home	379	19.3	55	10.4	0.110
Institutional	1587	80.7	475	89.6	**0.000**
Met with ASHA in last 12 months					
No	202	10.3	37	7.0	0.535
Yes	1764	89.7	493	93.0	**0.028**
Have MCP card					
No	308	15.7	20	3.8	0.148
Yes	1658	84.3	510	96.2	**0.000**
B. Household characteristics					
Type of family					
Joint	932	47.4	297	56.0	**0.010**
Nuclear	1033	52.6	233	44.0	**0.018**
Wealth tertile					
Poor	747	38.0	128	24.2	**0.003**
Middle	646	32.9	181	34.2	0.743
Rich	571	29.1	221	41.7	**0.001**
C. Community-level characteristics					
ASHA diary/VHIR updated					
Complete	962	48.9	357	67.4	**0.000**
Incomplete	914	46.5	155	29.2	**0.000**
Don't have diary	90	4.6	18	3.4	0.821
ASHA received supportive supervision from supervisor					
No	362	18.4	62	11.7	0.199
Yes	1604	81.6	468	88.3	**0.001**
Lack of motivation (ASHA)					
No	1412	71.8	420	79.2	**0.003**
Yes	554	28.2	110	20.8	0.110
Total	**1966**	**100**	**530**	**100**	

Note: Variables that did not show a statistically significant difference are not shown.

the critical need for robust communication and mobilization strategies. Additionally, our findings align with previous research that shows supportive supervision enhances the performance of ASHAs, not only by increasing their professional competence, but also by ensuring higher immunization coverage [48]. Enhanced motivation among ASHAs was also linked to improved immunization outcomes, as areas where ASHAs showed higher motivation levels observed lower rates of dropout. Thus, fostering a supportive and motivating environment for ASHAs and ensuring their organizational competence are essential for the success of immunization program.

Results also highlighted a significant positive association between the presence of parent-held vaccination records for their children (MCP card) and coverage of all basic vaccines. While most households had an MCP card, a significantly lower proportion of households living in areas with vaccine dropouts had such a record, compared to those living in areas with no dropouts. Like the ASHA health diaries, the MCP cards are essential for maintaining vaccination records and ensuring that children receive all the necessary immunizations [14,18,49–51]. Possession of an MCP card facilitates easier identification and communication during house-to-house visits by ASHAs, enabling more targeted and efficient follow-ups. MCP cards further help parents keep track of their child's vaccination schedule to ensure full immunization completion rates [18], which we found was a strong contributor to vaccination dropouts.

4.2. Service availability

In UP, child immunization services are predominantly delivered through outreach services using community-based platforms, called Village Health and Nutrition Days [52]. Although about 92 % of mothers reported these platforms as the 'usual' place for vaccination, we found wide geographic variations in immunization outcomes across UP. Immunization dropouts were not heavily clustered in specific locations but were distributed across ASHA areas, with some areas experiencing substantially higher dropout rates than others. While further geographic analysis is needed to conclusively map trends and specific geographic patterns, the dispersal of high-dropout areas throughout the state suggests that localized community engagement practices likely play a crucial role in immunization coverage. This disparity could also be attributed to differences in families' ability to access immunization services. For example, within the same ASHA areas, some children might receive vaccination from other health facilities if the community platform was not fully equipped with the required vaccines, while poorer families often depended solely on the community platforms.

Despite high availability of the required vaccines at the service delivery platforms (96.4 % readiness), immunization coverage gaps persisted, underscoring that service readiness is a requirement but does not guarantee high immunization uptake. The findings also highlight a wide variation in the immunization coverage between the blocks and within the blocks between the ASHA areas. A few blocks and ASHA areas disproportionately contributed to higher dropouts. These findings highlight that community-level interventions need to be context specific. Also, other factors such as socio-economic barriers and health system challenges play more critical roles in influencing the vaccination coverage. The high readiness level signifies a successful logistical aspect of vaccine delivery across rural UP but highlights the need for addressing deeper systemic and social issues to improve vaccination rates.

4.3. Parents' demographics

The child's family structure played a role in immunization coverage. We observed that a higher proportion of children from areas without dropouts resided in joint family structures. Living within an extended family network, where resources and responsibilities are shared, likely provides a stronger support network for mothers, thereby facilitating better access to healthcare information and services for their children [53], and ensuring children receive their vaccinations on time. The results further show that children born to more highly educated mothers are more likely to be fully immunized, a finding consistent with other global studies [54–56]. This may be because educated mothers are more likely to be aware of the importance of vaccination against vaccine-preventable diseases, are more proactive in making health decisions for their family, and have better access to media exposure, as observed in other contexts [15,19]. Similarly, children from wealthier families were more likely to be fully vaccinated than poorer families. While the result is consistent with previous studies [14–16,19], it is noteworthy that despite vaccination being offered free of charge and at monthly intervals at the village level in UP, children from economically disadvantaged families remain under-vaccinated [57]. However, in this study, we also found that both the proportion of children who were fully vaccinated by 15 months and those fully vaccinated by 12 months were relatively low, irrespective of mothers' education level or wealth, and even though most service delivery platforms had the vaccines available (96.4 %), placing greater emphasis on the reported uncertainty of parents about the immunization schedule and adequate mobilization by community health workers.

While the influence of education and wealth on full immunization coverage is evident, it is important to recognize that these factors operate within broader systemic contexts, including the organization and reliability of community health workers and vaccination centres. The relevance of families being well connected to the healthcare system is also highlighted in our finding that children born at health facilities were more likely to be fully immunized than those born at home. This aligns with previous research linking institutional delivery and higher immunization coverage [58,59]. Mothers who deliver in health institutions often receive detailed information about the schedule and the significance of completing the recommended vaccinations [18,60]. Moreover, children born in an institution are administered the BCG and polio vaccines before the infant is discharged [18,61].

Our study has a few limitations. Approximately 20 % of immunization records were based on the mother's recall, rather than an entry in the child's vaccination record, which can include social desirability bias as parents might report having their children vaccinated regardless of the correctness. However, a very small proportion of caregivers did not know or remember about the vaccines (0.3 % to 1.5 %) and will not be influencing estimation of immunization coverage to a large extent. Recall bias in vaccine uptake or date of vaccination is also possible, however, the survey was limited to children 0–15 months to ensure a relatively short recall period. The analysis is based on a cross-sectional survey; therefore, causal inferences cannot be made between full immunization coverage and other exposure variables. Despite these limitations, the study has several strengths. The analysis is based on a recent large population-based survey sample that provides estimates for four programmatically prioritized geographies. The study findings are generalizable for the settings aiming to improve the immunization coverage.

5. Conclusion

The study used a coverage cascade approach to highlight critical vaccine dropout points in the overall coverage of all basic vaccines, emphasizing the crucial role of effective mobilization of families and robust record-keeping. Complete and accurate parent-held vaccination records (MCP cards) and well-maintained patient records of community health workers (ASHA diaries), significantly improved immunization coverage by facilitating timely mobilization. Implementing a robust unitized digital system that tracks the vaccination schedule of children and the available immunization services within each ASHA area would reduce errors in calculating immunization due dates, manual record-keeping and could include automatic reminders for families on the immunization due date. Mobilization strategies that integrate robust data management within immunization programs are vital to ensure that children receive all recommended vaccinations and to maximize the protective benefits of vaccine programs. This is particularly important in rural areas, where systemic barriers and socio-economic disparities often hinder effective vaccine delivery. The disproportionate contribution to coverage drops by some geographies underscores the importance of identifying context-specific reasons for poor coverage and mitigation strategies. Policy-makers and program designers in similar rural-low-income contexts can leverage these insights to develop interventions that address the systemic inefficiencies and the specific needs of diverse communities, thereby improving health outcomes and advancing equitable immunization coverage.

CRediT authorship contribution statement

Ravi Prakash: Writing – original draft, Methodology, Formal analysis, Conceptualization. **Pradeep Kumar:** Writing – original draft, Formal analysis, Conceptualization. **Bidyadhar Dehury:** Writing – original draft, Formal analysis, Conceptualization. **Deep Thacker:** Writing – review & editing, Formal analysis. **Esther Shoemaker:** Writing – original draft. **Ramesh Banadakoppa Manjappa:** Methodology. **Shajy Isac:** Methodology, Conceptualization. **John Anthony:** Writing – review & editing. **Vasanthakumar Namasivayam:** Writing – review & editing. **James Blanchard:** Conceptualization. **Marissa Becker:** Writing – review & editing. **Ties Boerma:** Writing – review & editing, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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None

Annexures

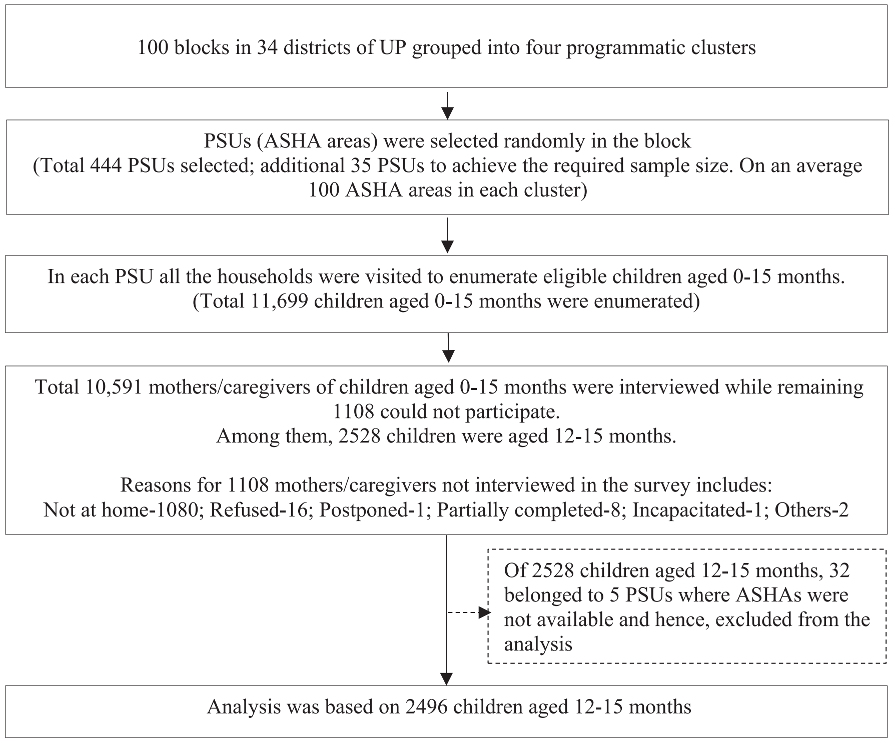

Fig. 1. Flow diagram depicting study sample construction.

Table A1
Sample distribution of the study participants and coverage of Penta3, MR1 and coverage of all basic vaccination children aged 12–15 months, Uttar Pradesh, 2021.

Characteristics	Sample profile		Coverage (%)			
	N	Percentage	Penta 3	MR-1	All Basic Vaccination	p-value@
A. Individual characteristics						
Child's sex						0.856
Boy	1301	52	85.0	70.0	67.6	
Girl	1195	48	84.1	70.7	68.1	
Mother's age (in years)						0.010
<24	757	30.5	84.3	70.2	67.7	
24–30	1486	60.1	85.4	71.4	68.9	
30+	253	9.4	80.5	64.0	61.4	
Mother's education						0.000
No Education	973	38.8	77.2	61.4	58.5	
<Secondary	685	27.4	88.0	74.1	71.7	
≥ Secondary	838	33.8	90.3	77.7	75.3	
Birth order						0.000
1	779	32.2	87.1	73.7	71.4	
2	700	28.6	86.6	71.4	68.6	
3	499	19.5	83.4	69.6	68.2	
4+	518	19.7	78.7	64.2	60.4	
Place of delivery						0.000
Home	434	17.5	73.8	59.9	56.3	
Institutional	2062	82.5	86.9	72.6	70.2	
Met with ASHA in the last 12 months						0.000
No	239	9.8	72.2	58.5	55.7	
Yes	2257	90.2	85.9	71.7	69.1	
Have MCP card[1]						0.000
No	328	12.9	50.6	38.9	34.0	
Yes	2168	87.2	89.6	75.0	72.8	
Decision making						0.050
Low	1132	46.1	82.4	67.7	65.0	
Medium	520	21.1	85.8	70.1	67.3	
High	817	32.8	87.1	74.3	72.1	

(*continued on next page*)

Table A1 (*continued*)

Characteristics	Sample profile		Coverage (%)			
	N	Percentage	Penta 3	MR-1	All Basic Vaccination	p-value[@]
Mobility						0.023
Low	1237	51.3	81.9	67.9	65.1	
Medium	394	15.5	86.0	73.9	70.3	
High	838	33	88.4	72.6	70.9	
B. Household characteristics						
Type of family						0.001
Joint	1229	49.3	86.1	72.4	69.9	
Nuclear	1266	50.7	83.2	68.4	65.8	
Caste						0.108
SC/ST	805	31	84.5	67.5	65.2	
OBC	1390	56.8	84.4	71.1	68.5	
Others	301	12.2	85.8	74.3	71.3	
Religion						0.000
Hindu	2139	84.8	86.1	72.1	69.8	
Non-Hindu	356	15.2	76.5	60.7	56.7	
Wealth tertile						0.000
Poor	875	32.9	79.6	63.7	61.3	
Middle	827	33.8	86.9	70.7	68.5	
Rich	792	33.3	87.4	76.6	73.6	
C. Community-level characteristics						
ASHA diary/VHIR updated						0.000
Complete	1319	51.2	88.0	74.4	72.3	
Incomplete	1069	44.6	81.9	66.9	63.9	
Don't have a diary	108	4.2	71.9	58.7	54.6	
ASHA received supportive supervision from supervisor in the last 30 days						0.000
No	424	16.8	76.9	57.3	54.7	
Yes	2072	83.2	86.2	73.0	70.5	
Lived catchment area (ASHA)						0.017
No	451	16.5	85.1	65.3	61.7	
Yes	2045	83.6	84.5	71.4	69.1	
Population covered by ASHA						0.676
≤1000	922	38.5	84.7	69.2	67.5	
1000–1500	1178	47.2	86.0	72.5	69.4	
1500+	396	14.4	79.8	66.3	63.5	
Lack of motivation (ASHA)						0.001
No	1832	71	86.0	72.2	70.0	
Yes	664	29	81.1	65.8	62.3	
Ever experienced verbal threats or intimidation						0.000
No	1970	79.4	86.7	72.5	70.3	
Yes	526	20.7	76.4	62.1	58.1	
Community Education						0.000
Low	1190	47.4	79.7	62.5	60.7	
High	1306	52.6	89.0	77.4	74.0	
Community wealth						0.000
Low	1031	37.4	80.8	63.4	62.3	
High	1465	62.6	86.9	74.5	71.6	
Total	**2496**	**100**	**84.6**	**70.4**	**67.8**	

[1]No category also includes cases where MCP card being reported 'yes' but could not be seen (5 % cases) and don't know (0.04 %) cases
[@]Chi-square test for all basic vaccination

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jvacx.2025.100613.

Data availability

Data will be made available on request.

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