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Spatial heterogeneity in the coverage of full immunization among children in India: Exploring the contribution of immunization card

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ABSTRACT

Background: This paper analyzes the mesoscale correlates and spatial heterogeneity in coverage of full immunization among children age 12–23 months in India using data from three rounds of National Family Health Survey conducted in 1998–99, 2005–06 and 2015–16.

Methods: The analytical methods used in this paper are predicted probabilities to explain changes in likelihood of full immunization among children over time. Propensity score matching to estimate contribution of vaccination card using counterfactual approach. Bivariate LISA maps and spatial error model have been used to understand spatial heterogeneity in full immunization coverage among children.

Results: Overall, 62 percent of children aged 12–23 months were fully immunized in 2015–16, that has increased from 41 percent in 1998–99. Availability of vaccination card at the time of survey and coverage of full immunization have strong positive association, which further increases with increasing wealth status in each of the three rounds of NFHS. Changes in predicted probability of full immunization among children indicate that the immunization program in India has made concerted efforts to reach out to all the socially deprived and economically marginalized children and ensured availability of immunization card and increased probability of full immunization. The counterfactual approach portrays that the estimated contribution of immunization card in the full immunization coverage were significantly higher in almost half of Indian states. Bivariate LISA Cluster map of full immunization have identified around 109 districts in the country as hotspots. When spatial weights were taken into consideration, the auto regression model noticeably became stronger in predicting the prevalence of full immunization. From the Spatial Error Model the estimated coefficients were −0.74 (p-value < 0.001) for those having no card, −0.09 (p-value < 0.001) for poor children and, 0.10 (p-value < 0.001) for those children who were from rural area were statistically significant.

Conclusions: Over the period, government efforts in ensuring immunization card to each eligible child, especially among poor and those living in rural areas, have contributed significantly in enhancing the age appropriate vaccination and full immunization among children in India.

1. Background

Universal immunization coverage is one of the most cost-effective child survival interventions in developing countries. Immunizing children against vaccine-preventable diseases can significantly reduce childhood morbidity and mortality. It is one of the most effective interventions to prevent the vulnerability of sickness, disability, and death among children (Andre et al., 2008). The benefits of immunization are not restricted only to improvements in children's health and life expectancy but also have a multifaceted social and economic impact at both community and national levels. As a result, a successful and efficiently tailored programme capable of reducing the burden of vaccine preventable diseases (VPDs) would contribute significantly to achieving the sustainable goal 3 (SDG3) by implementing two-fold policies to highlight the full coverage of children's immunizations. First increasing the proportion of the target population covered by all vaccinations included in the national programme and second, improving the universal health coverage, where 1 out of 16 tracer metrics is complete

Abbreviations: NFHS, National Family Health Survey; UIP, Universal Immunization Program; PSM, Propensity Score Matching; LISA, Local Indicators of Spatial Analysis; OLS, Ordinary Least Square; SLM, Spatial lag Model; SEM, Spatial Error Model.

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immunization for children to assess the capacity of the national plan to provide extensive and equal coverage services (Arora, 2017).

India has the most significant number of live births globally, more than 26 million a year, and accounts for more than one-fifth of total child deaths worldwide. Recognizing the importance of vaccine-preventable childhood diseases, India has made concerted efforts to ensure full immunization among children over the last three decades through the Universal Immunization Program (UIP) that provides free childhood vaccines, with proactive support from WHO and UNICEF. Besides the Universal Immunization Programme, India has also adopted various innovations to minimize no or partial immunization even among socially marginalized and economically deprived groups, including those living in remote rural areas. As a result, about nine million immunization sessions are organized each year to target young children and pregnant women under the routine immunization (RI). Despite these efforts, the country still accounts for the largest number of children who are not immunized (7.4 million) or having partial immunization coverage (Immunization, 2017; Sur, 2016).

Meanwhile, there has been a perceived gap in the full immunization coverage in the programme data and those estimated through national level household surveys conducted across different states. These perceptions are mostly based on increasing gaps in the estimated prevalence of full immunization recorded from immunization cards and those based on mother's recall as estimated over different rounds of NFHS in India.

In fact, vaccination card is a critical tool in ensuring that a child receives all recommended vaccinations on schedule. Appropriate and timely vaccination documentation helps ensure not only that person in need of recommended vaccine doses receive them but also that adequately vaccinated children do not receive excess doses. However, health being the subject of state governments, the coverage of immunization card is not uniform across different States/UTs (IIPS and ICF, 2017). The major research questions are, whether women are not able to precisely recall and report different doses of vaccinations administered to their children in the absence of immunization card. In the existing demand supply framework, whether immunization coverage varies by districts/States/region. Therefore, this paper analyzes the spatial heterogeneity in coverage of full immunization and contribution of immunization card in the full immunization coverage among children in India.

2. Data

This paper has used data from three rounds of National Family Health Surveys (NFHS) conducted in 1998–99, 2005–06 and 2015–16. In each round of NFHS, information on vaccination were collected either from the child's health card or by reporting of mothers based on their recall. Total 33,026 children of age 0–35 months in NFHS-2, 51,555 of age 0–59 months in NFHS-3 and 259,627 of age 0–59 months in NFHS-4 were covered among them the analysis were concentrated on the sample 10,879 in NFHS-2, 10,074 in NFHS-3 and 51,544 in NFHS-4 of children age 12–23 months. The contents and coverage of NFHS in India have been changing over time but the basic contents on childhood vaccinations have been retained to maintain comparability overtime despite of expanding contents and coverage of NFHS. A brief description on data, survey designs and quality check measures have been presented in the National Report of NFHS-4 (IIPS and ICF, 2017)

2.1. Description of the variables

2.1.1. Dependent variables

The dependent variable used in this study is full immunization among children age 12–23 months. Full vaccination coverage has been computed for the children age 12–23 months, who received specific vaccines at any time before the survey (according to a vaccination card or the mother's report). To have received all basic vaccinations, a child must receive at least: one dose of BCG vaccine, which protects against tuberculosis, three doses of DPT or Penta vaccine, which protects against diphtheria, pertussis (whooping cough), and tetanus, three doses of polio vaccine and one dose of measles or MR or MMR vaccine. The variable categorized in to two category yes and no.

2.1.2. Independent variables

Independent variables included health card seen during reporting of immunization in the two category (not seen and seen card) educational attainment in years (No education, primary, secondary and higher), place of residence (rural and urban), religion (Hindu, Muslim, Christian, Sikh, Others), wealth index (poorest, second, middle, fourth, richest), and Caste group (Scheduled Caste (SC), Scheduled Tribe (ST), Other Backward Class (OBC), non-ST/SC/OBC). Wealth index was used as a proxy measure for assessing the economic status (poorest, poorer, middle, richer, richest).

3. Methods

In this manuscript, researchers have used some of descriptive statistics, including predicted probabilities to understand the magnitude of changes in the full immunization coverage among children age 12–23 months in the past two and half decades i.e from NFHS-2 to NFHS-3 and NFHS-3 to NFHS-4, after adjusting the effects of some socio-demographic and contextual characteristics. In addition Propensity score matching (PSM) has been used to find the contribution of immunization cards in full immunization coverage and spatial autocorrelation and auto regression have been used to analyze spatial heterogeneity, with special focus at the contribution of immunization cards in full immunization coverage in India. For completeness, a brief description of these methods are presented in this section.

3.1. Propensity score matching (PSM)

Propensity Score Matching (PSM) analysis is a counterfactual model used to compute the effect of immunization card on full immunization among children age 12–23 months controlling all other background characteristics and biases. This model gives us the actual impact of the treatment or intervention, and it does not introduce any bias (Austin, 2011; Mason, Sabariego, Thắng, & Weber, 2019).

3.2. Spatial analysis

For spatial analysis in the coverage of full immunization, Univariate and Bivariate Moran's I statistic with a set of regression models have been in use. Moran's I is the measure of spatial autocorrelation and it is a generalization of Pearson's correlation coefficient (Anselin, 1995; Chen, 2013).

Spatial clusters have been identified by using Univariate and Bivariate LISA (Local Indicators of Spatial Analysis) maps. A set of regression models have been used in order to analyze the significant correlates of full immunization coverage among children. Spatial OLS (Ordinary Least Square) regression was used to see the extent of autocorrelation in the error term. Since the OLS confirmed spatial autocorrelation in its error term, we further estimated spatial lag model (SLM) and Spatial Error Model (SEM). The underlying assumption of a spatial lag model is that the observations of the dependent variable are affected in the neighborhood areas, whereas the spatial error model is used to consider the effect of those variables, which are not present in the regression model but have an effect on the outcome variable. The basic difference between the two models is that the spatial lag model unlike spatial error model does not consider the spatial dependence in the error term. After analyzing the AIC (Akaike Information Criterion) value, we found that the spatial error is the best fit model for the study. Spatial error model on the other hand, considers the contribution of omitted variables which are not included in the model but can have significant effect in the analysis (Khan & Mohanty, 2018; Khan, Shil, & Prakash, 2018).

ArcGIS version 10.4, GeoDa version 1.12, STATA 13.1 and MS office package were used for analyzing the data throughout the study.

4. Results

In India, the percentage of children age 12–23 months who received all basic vaccination increased from 40 percent in 1998–99 to 44 percent in 2005–06 and the most recent wave of NFHS find that the full immunization coverage has now increased to 62 percent in 2015–16 (Table 1). Over a period from NFHS-2 to NFHS-4 it has been seen that the gender gap in full immunization among children age 12–23 months and having immunization card is narrowing and by 2015–16 almost equal proportion of boys and girls in India have been fully vaccinated and have immunization cards. The immunization card, which was requested to show during survey and full immunization coverage, increases with increasing mother's schooling in all three rounds of NFHS. Children age 12–23 months whose mothers were better educated had received all basic vaccinations are 71 percent, compared with 52 percent of children whose mothers have no schooling in NFHS-4. The percentage of children who received full vaccination increased more in rural areas (from 35% to 62%) than in urban areas (from 55% to 64%). Similarly, the use of immunization card, which has seen during survey, has also increased more in rural area than in urban areas. Christian children were more likely to have received all basic vaccinations than the children of Hindus and Muslims in each of the three rounds of NFHS. Wealth index shows the positive impact on full immunization as results portrays that availability of vaccination card and coverage of vaccination increases with increasing wealth status in all three rounds of NFHS. In NFHS-4, 70 percent of children age 12–23 months from the households in the highest wealth quintile received all basic vaccinations, compared with 53 percent of children from households in the lowest wealth quintile (Table 1).

All the mothers interviewed in the survey were not able to produce a vaccination card for their child at the time of the interview and hence the immunization status of their children were estimated based on information collected from mothers, which may have the problem of recall bias. The proportion of children having full immunization among those whose mothers reported their vaccination status declined from 28 percent in NFHS-2 to 26 percent in NFHS-4 (Fig. 1). Among all those children age 12–23 months, whose vaccination card was available at the time of survey, the proportion of children who were fully vaccinated increased from 69 percent in NFHS-2 to 83 percent in NFHS-4. Thus, availability of immunization card at the time of survey matters significantly in recording of full immunization coverage.

Results presented in Table 2 portray the predicted probability of full immunization coverage among children age 12–23 months estimated with respect to recording of vaccination from health/immunization card, wealth quintile, place of residence and mother's educational attainment. It is evident that the predicted probability of full immunization coverage declined by 11 percent during 1998–2005, when recorded based on mother's recall due to non-availability of immunization cards. The corresponding decline during 2005–15, however, was even less than one percent (0.7%), which may be attributed to the increasing maternal education and awareness to full immunization. The pattern in full immunization coverage gets reversed when recorded it from immunization card rather than mother's recall. The predicted probability of full immunization coverage increased by 8 percent during 1998–2005 and 16 percent during 2005–15. Further, it is evident from the changes in the predicted probability of full immunization among children by their mother's education, urban-rural place of residence and wealth quintiles of the households that the immunization program in India has made concerted efforts to reach out to all the vulnerable children, especially among those who are socially deprived, economically marginalized and belonging to the households facing various forms of social exclusions. Further, it is evident from the results presented in Table 2 that the predicted probability of full immunization coverage among rural children age 12–23 months increased by 3 percent during 1998–2005, that further increased to 43 percent during 2005–15. The predicted probability of full immunization coverage among children of mothers without any formal schooling or having no educational

Table 1
Percentage of children age 12–23 months who received full vaccination at any time before the survey, and percentage with a vaccination card that has seen during survey by selected background characteristics, India, 1998–99 to 2015–16.

	Seen Card			Full Immunization		
Background Characteristics	NFHS-2 (1998–99)	NFHS-3 (2005–06)	NFHS4 (2015–16)	NFHS-2 (1998-99)	NFHS-3 (200506)	NFHS-4 (2015–16)
Sex of the Child						
Male	34.5	38.8	62.8	41.0	45.7	62.3
Female	33.0	36.1	63.6	38.8	41.9	62.1
Education						
No education	22.8	25.1	52.1	25.2	26.3	51.7
Primary	39.7	40.3	61.9	46.3	46.1	60.6
Secondary	48.3	50.9	68.7	59.0	62.3	66.7
Higher	53.1	58.5	68.8	69.4	80.6	70.6
Residence						
Urban	46.0	46.2	65.3	55.5	58.1	64.0
Rural	30.2	34.5	62.4	35.3	38.9	61.5
Caste						
SC	31.4	34.8	65.0	38.3	39.7	63.4
ST	24.4	27.4	56.2	25.1	31.3	56.1
OBC	33.5	34.5	62.9	41.3	40.7	62.0
Others	38.1	45.0	64.3	44.0	53.8	63.0
Religion						
Hindu	33.8	37.4	63.9	40.6	44.8	63.2
Muslim	30.6	36.4	57.7	30.3	36.6	55.6
Christian	42.4	44.1	68.4	56.4	56.4	62.5
Others	42.7	41.9	76.6	63.4	55.9	74.8
Wealth Index						
Poorest	36.3	25.5	53.0	38.5	24.5	53.2
Poorer	36.3	32.3	63.0	36.5	33.4	60.9
Middle	31.9	38.9	65.3	35.8	47.2	64.4
Richer	31.7	43.0	69.0	40.4	55.9	67.0
Richest	34.4	55.9	70.2	44.9	71.7	70.0
Total	**34.6**	**37.5**	**63.2**	**40.0**	**43.9**	**62.3**

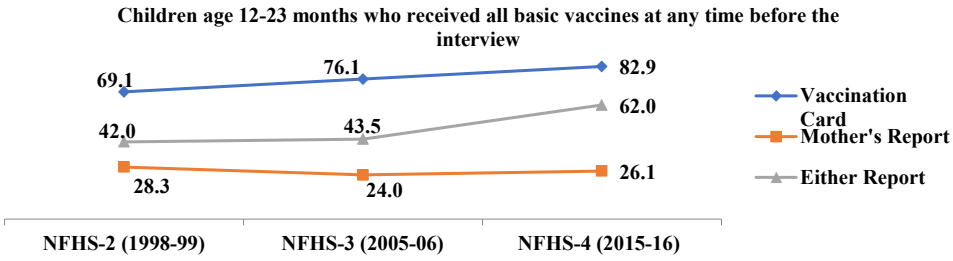

Fig. 1. Percentage of children age 12–23 months who received all basic vaccinations at any time before the survey based on vaccination card or mother's report, India, 1998–99 to 2015–16.

Table 2
Predicted probability of full Immunization among children age 12–23 months estimated with respect to seen vaccination card, wealth quintile, place of residence and mother's education, India, 1998–99 to 2015–16.

	Children age less than 3 years			Children age less than 5 years		
	NFHS-2 (1998–99) Predicted Probability [CI]	NFHS-3 (2005–06) Predicted Probability [CI]	Change 1999–2006	NFHS-3 (2005–06) Predicted Probability [CI]	NFHS-4 (2015–16) Predicted Probability [CI]	Change 2005–16
Health card						
Not seen	0.304 [0.29–0.32]	0.271 [0.26–0.28]	0.033	0.271 [0.26–0.28]	0.269 [0.26–0.28]	0.002
Seen card	0.663 [0.65–0.68]	0.715 [0.70–0.73]	−0.051	0.715 [0.70–0.73]	0.825 [0.80–0.83]	−0.111
Wealth Index						
Poorest	0.415 [0.39–0.44]	0.361 [0.34–0.38]	0.054	0.361 [0.34–0.38]	0.601 [0.59–0.61]	−0.240
Poorer	0.401 [0.38–0.42]	0.389 [0.37–0.41]	0.012	0.389 [0.37–0.41]	0.611 [0.60–0.62]	−0.223
Middle	0.426 [0.40–0.45]	0.469 [0.45–0.49]	−0.043	0.469 [0.45–0.49]	0.629 [0.62–0.64]	−0.160
Richer	0.486 [0.46–0.51]	0.493 [0.47–0.51]	−0.007	0.493 [0.47–0.51]	0.633 [0.62–0.64]	−0.140
Richest	0.497 [0.47–0.53]	0.535 [0.51–0.56]	−0.038	0.535 [0.51–0.56]	0.649 [0.64–0.66]	−0.113
Residence						
Urban	0.469 [0.45–0.49]	0.439 [0.42–0.46]	0.030	0.439 [0.42–0.46]	0.607 [0.60–0.61]	−0.168
Rural	0.427 [0.42–0.44]	0.439 [0.43–0.45]	−0.012	0.439 [0.43–0.45]	0.628 [0.62–0.63]	−0.189
Education						
No education	0.345 [0.33–0.36]	0.353 [0.34–0.37]	−0.009	0.353 [0.34–0.37]	0.588 [0.58–0.60]	−0.235
Primary	0.484 [0.46–0.51]	0.455 [0.43–0.48]	0.029	0.455 [0.43–0.48]	0.617 [0.61–0.63]	−0.163
Secondary	0.542 [0.52–0.56]	0.524 [0.51–0.54]	0.018	0.524 [0.51–0.54]	0.633 [0.63–0.64]	−0.109
Higher	0.592 [0.56–0.63]	0.627 [0.59–0.67]	−0.035	0.627 [0.59–0.67]	0.663 [0.65–0.67]	−0.036

In NFHS-2 information on immunization were collected for children below age 3 years but full immunization was computed for all those children age 12–23 months at the time of survey.

attainment increased to 67 percent in 2005–15 from the corresponding increase of 3 percent in 1998–2005. These findings indicate the important of recording immunization data from the health cum immunization card of children.

Table 3 presents the contribution of having immunization card on full immunization coverage using propensity score matching applied with counterfactual approach and nearest neighborhood method. This method provides estimates of prevalence of full immunization among children age 12–23 months, without matching two groups i.e those having and not having immunization card, average treatment effect (full immunization) on the treated (ATT), i.e. those having immunization card, average treatment effect on the untreated (ATU), average treatment effect (ATE) showing the difference in estimates of full immunization between treatment and control groups after matching for various background characteristics. Results portrays an unmatched difference in treatment and control groups as 56 percent, which has increased to 62 percent after matching the two groups by taking urban-rural place of residence, caste, religion, wealth quintiles and mother's education. The average effect of having immunization card on coverage of full immunization i.e. average treatment effect on treated (ATT) has been 71 percent. After matching, the value of ATT is around 82 percent in treatment group and 11 percent in control group. It means that, those children whose immunization related information were recorded from immunization card, if they were not having immunization card and information would have been collected based on mother's recall, the estimated prevalence of full immunization would have been only 11 percent. Average treatment effect on untreated shows that children who did not have immunization card, if they had immunization card, the estimated prevalence of full immunization would have increased from 26 percent to 73 percent. ATE of 62 percent shows the estimated difference in full immunization among children whose immunization records were collected with the help of immunization card and those based on mother's recall after matching for five important predictors of full immunization included in the model. The lowest contribution of the immunization card in reporting of full immunization among children has been estimated in the state Uttarakhand followed by Kerala, where female literacy and their educational attainments are substantially higher than other states. Other major states having relatively lower estimated contribution of immunization card in the full immunization of children are Bihar, Jharkhand, Rajasthan, and Uttar Pradesh (between 40 and 44 percent). On the other hand, states having the largest estimated contribution of immunization card in coverage of full immunization among children after matching for various background characteristics like wealth quintiles, mother's education, urban-rural place of residents, religion, caste etc., are namely Odisha (75%), Gujarat (69%), Andhra Pradesh (68%), Himachal Pradesh (67%), each of Jammu and Kashmir and Madhya Pradesh (62%), Karnataka (54%) and Maharashtra (53%).

Given the research hypothesis of no spatial clustering in full immunization among children age 12–23 months across 640 districts in India, results analyzed in this section have two major components. First, bivariate LISA maps along with Moran-I and second, the spatial auto regression portraying spatial dependence of full immunization on the various background and behavioral characteristics including mother's presenting the immunization card of their children. Fig. 2(A) portrays bivariate LISA cluster map of full immunization among children age

Table 3
Contribution of immunization card in reporting of full immunization among children age 12–23 months using propensity score matching (PSM), 2015–16.

	Unmatched			ATT			ATU			ATE
	Treated	Controls	Difference	Treated	Controls	Difference	Treated	Controls	Difference	
India	**0.82**	**0.26**	**0.56**	**0.82**	**0.11**	**0.71**	**0.26**	**0.73**	**0.47**	**0.62**
Andhra Pradesh	0.90	0.24	0.65	0.90	0.20	0.70	0.24	0.88	0.64	0.68
Arunachal Pradesh	0.70	0.06	0.64	0.70	0.09	0.61	0.06	0.66	0.60	0.60
Assam	0.75	0.17	0.58	0.75	0.19	0.56	0.17	0.78	0.61	0.58
Bihar	0.81	0.36	0.45	0.81	0.42	0.39	0.36	0.77	0.41	0.40
Chhattisgarh	0.91	0.37	0.54	0.91	0.49	0.42	0.38	0.93	0.55	0.46
Goa	0.94	0.20	0.74	0.95	0.19	0.76	0.20	1.00	0.80	0.77
Gujarat	0.83	0.17	0.66	0.83	0.19	0.65	0.17	0.92	0.74	0.69
Haryana	0.83	0.16	0.67	0.83	0.23	0.6	0.16	0.82	0.66	0.62
Himanchal Pradesh	0.85	0.31	0.54	0.85	0.13	0.72	0.31	0.87	0.56	0.67
Jammu and Kashmir	0.85	0.16	0.69	0.85	0.24	0.61	0.16	0.81	0.65	0.62
Jharkhand	0.79	0.33	0.46	0.79	0.32	0.47	0.33	0.72	0.39	0.44
Karnataka	0.80	0.29	0.51	0.80	0.26	0.54	0.29	0.82	0.52	0.54
Kerala	0.89	0.44	0.45	0.88	0.54	0.34	0.44	0.79	0.35	0.34
Madhya Pradesh	0.81	0.21	0.60	0.81	0.20	0.61	0.21	0.83	0.62	0.62
Maharashtra	0.80	0.21	0.60	0.80	0.21	0.59	0.21	0.74	0.53	0.53
Manipur	0.80	0.28	0.52	0.80	0.42	0.38	0.28	0.68	0.41	0.39
Meghalaya	0.84	0.2	0.64	0.84	0.24	0.60	0.20	0.75	0.56	0.58
Mizoram	0.74	0.19	0.55	0.74	0.10	0.64	0.19	0.67	0.48	0.48
Nagaland	0.63	0.09	0.55	0.63	0.23	0.40	0.09	0.59	0.50	0.45
Delhi	0.83	0.32	0.51	0.83	0.44	0.39	0.33	0.75	0.43	0.40
Odisha	0.93	0.20	0.73	0.93	0.17	0.76	0.20	0.90	0.70	0.75
Punjab	0.96	0.39	0.57	0.96	0.46	0.50	0.39	0.93	0.54	0.50
Rajasthan	0.79	0.30	0.49	0.79	0.38	0.41	0.30	0.78	0.48	0.44
Sikkim	0.96	0.29	0.67	0.97	0.08	0.89	0.29	0.97	0.68	0.85
Tamil Nadu	0.81	0.23	0.58	0.81	0.25	0.55	0.23	0.78	0.55	0.55
Tripura	0.74	0.08	0.65	0.74	0.07	0.67	0.08	0.72	0.64	0.66
Uttar Pradesh	0.74	0.29	0.45	0.74	0.30	0.44	0.29	0.65	0.36	0.40
Uttarakhand	0.77	0.38	0.38	0.77	0.48	0.28	0.38	0.69	0.31	0.29
West Bengal	0.92	0.33	0.59	0.92	0.32	0.60	0.33	0.90	0.57	0.59
Telangana	0.89	0.22	0.67	0.89	0.22	0.67	0.23	0.88	0.66	0.67

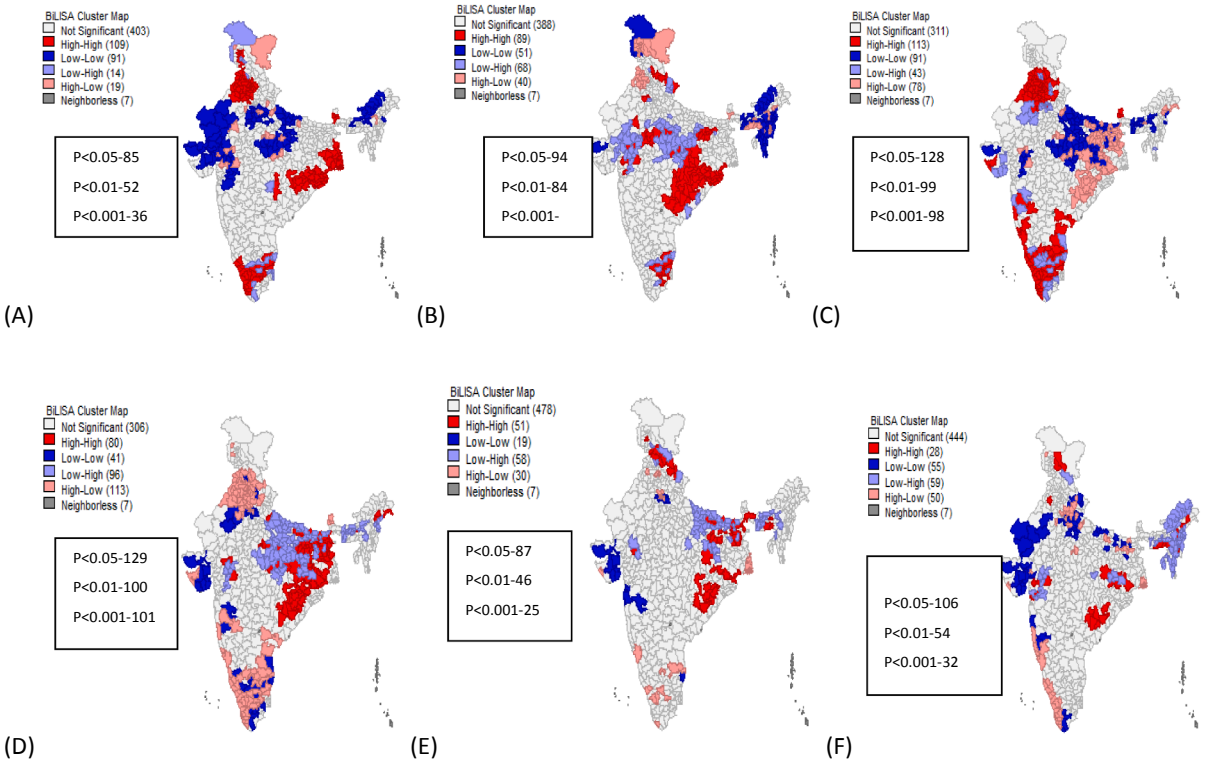

Fig. 2. Bivariate Lisa (Cluster and Significance) maps depicting spatial clustering and spatial outliers of full Immunization among children aged 12–23 months by selected background characteristics across 640 districts of India, 2015–16.

12–23 months by availability of their immunization card. There are around 109 districts in the country, which were emerged as hotspots, and having higher degree of spatial clustering with significant spatial autocorrelation (0.38) between these two variables. The spatial clustering were highly significant in 36 districts ($p < 0.001$), followed by another 52 districts ($p < 0.01$) and 85 districts ($p < 0.05$). Most of such districts are located in states like Andhra Pradesh, Tamil Nadu, Punjab, Haryana, Sikkim and some parts of West Bengal and Odisha. These findings indicate that the EAG states, where maternal and child health have been prioritized with a number of vertical interventions under NRHM are still required concerted efforts.

Further by Hindu religion (Fig. 2B), there were around 89 districts from Andhra Pradesh, Telangana, Odisha and West Bengal with very significant spatial clustering with full immunization among children. For the children coming from non-poor households, there were 113 districts with high clustering with full immunization, which were mostly located in states namely Punjab, Haryana, Himanchal Pradesh and Kerala have higher degree of clustering (Fig. 2C). The spatial clustering were highly significant in 98 districts ($p < 0.001$), followed by another in 99 districts ($p < 0.01$) and 128 districts ($p < 0.05$). While poor category of children having around 80 district having higher degree of spatial clustering, which were mostly were located in states Odisha, West Bengal and Bihar (Fig. 2d). The spatial clustering were highly significant in 101 districts ($p < 0.001$), followed by another 100 districts ($p < 0.01$) and 129 districts ($p < 0.05$). Furthermore, bivariate Lisa cluster Map of full immunization by rural residence (Fig. 2e), shows around 51 district of the country having higher degree of spatial clustering mostly were located in states like Uttarakhand, Odisha and Meghalaya. The spatial clustering between them were highly significant in 25 districts ($p < 0.001$), followed by another 46 districts ($p < 0.01$) and 87 districts ($p < 0.05$). By SC/ST category of the children, there were around 28 districts mostly located in Odisha, Jammu and Kashmir and Meghalaya having higher degree of spatial clustering. The spatial clustering were highly significant in 32 districts ($p < 0.001$), followed by another 54 districts ($p < 0.01$) and 106 districts ($p < 0.05$). These findings highlight tremendous heterogeneity in the full immunization coverage among children in India by various background and behavioral characteristics.

The spatial autocorrelation with the application of bi-variate LISA maps put forward the need for analyzing the spatial dependence in the prevalence of full immunization among children aged 12–23 months across different districts of India (Fig. 3). To decide the suitability of the model to analyze spatial dependence, two sets of test on Log Ranges Multipliers (LM) and Robust LM were used with the help of the White test in the OLS model. The White test produces the significance of LM (lag) as well as LM (error). As a result, Robust LM (lag) and Robust LM (error) have been compared. Relatively larger value of LM (error) than the LM (lag) and relatively larger value of adjusted R^2, (explaining the better model adequacy) and lower values of Akaike info criterion and Schwarz criterion, (explaining better suitability of the model), guided us to apply LM (error) model to analyze the spatial dependence of full immunization among children with various predictors included in the model. Results of the spatial error model on the spatial dependence of full immunization among children are presented in Table 4. The findings portray that in the prevalence of full immunization among children in India, geography matters significantly. When spatial weights are taken into consideration, the spatial regression model becomes stronger in predicting the full immunization coverage among children. The estimated coefficients were −0.74 (p-value < 0.001) for those having no card, −0.09 (p-value < 0.001) for poor children and, 0.10 (p-value < 0.001) for those children who were from rural area were highly statistically significant.

5. Discussion

Findings of the present study focused on the spatial heterogeneity in

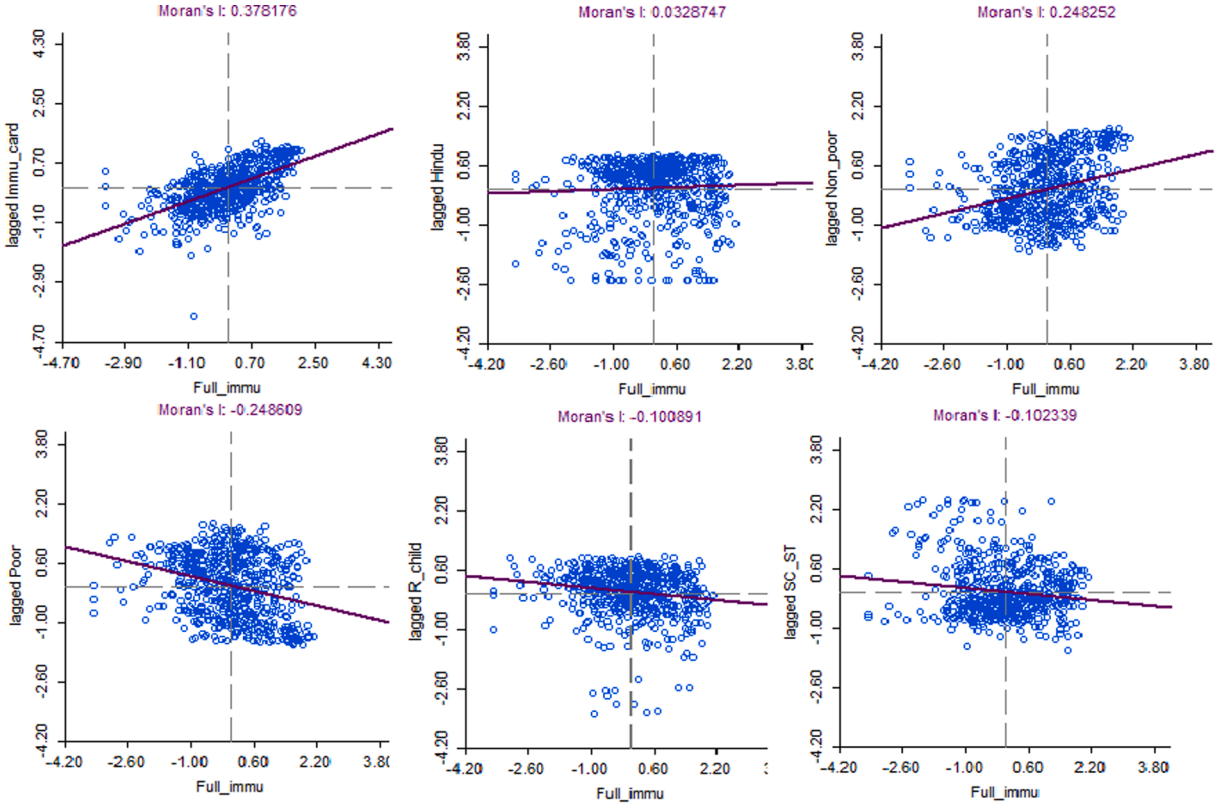

Fig. 3. Scatter Plot for the Bivariate local Moran's I portraying spatial autocorrelation among full Immunization among children age 12–23 months with various predictors namely seen immunization card, Hindu Children, children from non-poor and poor households, rural residence and coming from SC/ST households.

Table 4
Special OLS and Spatial Error model to assess the association between full Immunization and selected background variables among children age 12–23 months, 2015–16.

Variables	A spatial OLS for full Immunization		Spatial Error Model for full Immunization	
	Coefficients	Probability	Coefficient	Probability
No Card	−0.83	0.00	−0.74	0.00
Muslim	−0.01	0.80	0.05	0.06
Poor	−0.04	0.00	−0.09	0.00
Rural Children	0.10	0.00	0.10	0.00
SC/ST caste group	−0.03	0.08	0.02	0.40
Constant	87.42	0.00	82.88	0.00
Number of observation	640.00		640.00	
Log likelihood	−2424.53		−2396.62	
AIC	4861.06		4805.23	
R square	0.65		0.69	
Lag Coefficient (Lambda)			0.44	0.00
Breusch-Pagen test	213.14	0.00	230.96	0.00
Likelihood ratio test			55.83	0.00

coverage of full Immunization among children in India and contribution of having immunization card at the time of survey in the reported coverage of full immunization. The proportion of fully immunized children of age 12–23 months has increased over a decade and cover only 62 percent children in NFHS-4. This finding indicates that despite the longstanding effort to achieve the goal of universal immunization there is huge gap in targets and achievements in immunization coverage in India. It is evident from the findings that, both the proportion of children with health cards and full immunization coverage among children age 12–23 months have increased over time. Further, children with health cards were significantly more likely to be fully immunized than children without immunization cards. In recent Coverage Evaluation Survey (CES) 2009, a nationwide survey covering all states and union territories of India conducted for UNICEF, it was observed that about 52 percent of mothers had an immunization card. Other previous studies also indicated in the similar way that the immunization coverage differs significantly by possession of health card (Coverage Evaluation, 2009; Kumar & Mohanty, 2011). Sex-related inequality was non-existent, as male and female children presented the same level of coverage while the other previous studies has clearly noted such behaviour of families in neglecting and discriminating against girl children in case of immunization despite of the vaccines are freely available (Gatchell et al., 2008; Pande, 2003; Patra, 2009; Singh 2012, 2013). Parents are the primary health decision-makers for their children, their knowledge and attitude towards immunization have a great impact on the immunization status of their children. These findings are similar to some other studies which concluded that uneducated mothers are less likely to have provide full immunization to their children (Lee & Mason, 2005; Mathew, 2012; Vikram, Vanneman, & Desai, 2012). An important benefit of increased literacy and school enrollment, particularly for girls, is the subsequent spillover to the health of their children (Lee & Mason, 2005). According to WHO (2018), the inequality in household economic status was pervasive: children from poor households were less likely to receive vaccinations than those from richer households (WHO, 2018). Over the years, there has been a decline in the urban-rural differences as well as gender differences in the full immunization coverage in India, which is primarily due to concerted efforts under Mission Indradhanush to enhance reach and penetration of immunization programme to rural and remote areas, with especial focus at socially deprived and economically marginalized population. The immunization program in the country have emphasized supportive supervision, addressing contra-indicators and side-effects of immunization, which have resulted in minimizing different types of misconceptions about immunization. Earlier, the open vial policy, as recommended by WHO, had a protocol that the opened multi-dose vials must be discarded after 6 h or at the end of the immunization session, whichever comes first. Because of this pre-condition the sealed vial is opened only in case of at least 5 children are available, if it is less than five children then service providers were not giving vaccine to those children. However, under the mission Indradhanush, this stringent protocol has been changed and which has helped in reducing the partial immunization among children.

To strengthen and re-energize the programme and achieve full immunization coverage for all children and pregnant women at a rapid pace, the Government of India launched "Mission Indradhanush" in December 2014 (Gurnani et al., 2018; IIPS and ICF, 2017; Lahariya, 2014; Vashishtha, 2012). Results of NFHS-5 (2019–20) are the true reflection of the impact of mission Indradhanush in enhancing coverage of full immunization among children in India, which has been primarily due to ensuring immunization card to each eligible children, increasing outreach program with supportive supervision, increasing parental awareness, minimizing misconceptions about immunization and improved quality of side effect management.

Most of the states, where coverage of full immunization among children age 12–23 months in NFHS-4 (2015–16) was low, have achieved significantly higher prevalence of full immunization during the last five years. The state of Nagaland, where only 35 percent of children age 12–23 months were fully immunized in 2015–16, has registered a significant increase in NFHS-5 (2019–20) with 57 percent coverage of full immunization based on information either from immunization card or mother's recall and 71 percent based on information from immunization card only. Similarly, the full immunization coverage in Assam has increased from 47 percent in 2015–16 to 66 percent in 2019–20, which increases further 72 percent if considered information based on card only. Gujarat (50%), Mizoram (51%) and Tripura (55%) are another states where the full immunization coverage among children age 12–23 months have registered profound increase during the phase of mission Indradhanush, as estimated in NFHS-5 (2019–20). The corresponding prevalence of full immunization among children in these states are 76 percent, 73 percent and 68 percent respectively, which further increase to 85 percent, 84 percent and 74 percent if considered information from card only. Similarly, other states which registered substantial increase in full immunization coverage among children age 12–23 months during the last four years are Maharashtra (from 56 to 73%), Bihar (62 to 70%), Karnataka (63 to 84%) Andhra Pradesh (65 to 72%) and Telangana (68 to 79%). As expected, these states have registered further increase in full immunization coverage among children age 12–23 months if consider the information from immunization card only, which are 82 percent in each of Maharashtra and Bihar; 89 percent in Karnataka; 88 and 87 percent in Andhra Pradesh and Telangana respectively. These results clearly indicate a profound increase in full immunization coverage among children age 12–23 months in the last four years in each of the State/UT covered in the first phase of NFHS-5 (2019–20). Among other factors, ensuring immunization card has contributed significantly, where women were frequently recalled about the due dates of immunization of their children.

The states having largest estimated contribution of immunization card in the full immunization coverage among children age 12–23 months were Odisha, Gujarat, Andhra Pradesh, Himachal Pradesh, J&K, Madhya Pradesh, Karnataka and Maharashtra. It is worth mentioning that the state-level differences may be expected to exert an influence on the individual-level and community level predictors of childhood vaccination, especially since many state-level policies and programs directly affect immunization services. Such community level factors may influence parental decisions for the receipt of preventive services (such as vaccination for their children) independent of individual-level characteristics (Mathew, 2012; McCall-Hosenfeld, Weisman, Camacho, Hillemeier, & Chuang, 2012). A study on role of the private sector in vaccination service delivery in India concluded that certain low income states like Uttar Pradesh, Rajasthan, Madhya Pradesh, Orissa, Assam and Bihar have low private as well as public sector vaccination coverage.

"The private sector's role has been limited primarily to the high income states as opposed to these low income states where the majority of Indian children live. Urban areas with good access to the private sector and the ability to pay, increases the Indian population's willingness to access private-sector vaccination services" (Sharma, Kaplan, Chokshi, & Zodpey, 2016).

It is evident from the results of spatial clustering in the prevalence of full immunization coverage and mothers presented immunization card at the time of survey is highly significant. These findings are strongly indicative of the fact that, the lack of full immunization coverage among children age 12–23 months not only persists because of lack of awareness among parents and lack of access to vaccination as per immunization scheduled. This may also be because of mother's failing to follow the immunization card and due dates of vaccination to their children in addition to failing in, recalling the details of vaccinations to their children, while reporting.

6. Conclusions

The slow progress and a wider socio-economic and spatial heterogeneity in full immunization coverage among children age 12–23 months in India during 1998–99 to 2015–16 was a matter of concern, particularly when compared to the remarkable improvements in maternal and child health inclusive of institutional deliveries. However, the pace of improvement has been much appreciative during 2006–16 where there has been increased focus at children coming from socially marginalized and economically deprived groups, which are adequately evident from the changes in predicted probability of full immunization among children in India. Further, the initiatives taken in the Mission Indradhanush, initiated in 2014 have made significant contribution in enhancing full immunization coverage in 2019–20, especially among states where the coverage was very low in 2015–16. These changes can be attributed to the concerted efforts under Mission Indradhanush to enhance reach and penetration of immunization programme to rural and remote areas, with especial focus at socially deprived and economically marginalized population. The immunization program in the country have emphasized supportive supervision, addressing contra-indicators and side-effects of immunization, which have resulted in minimizing different types of misconceptions about immunization. Further, ensuring immunization card to each eligible child for age appropriate vaccination has contributed significantly in enhancing full immunization among children age 12–23 months in India.

7. Strengths and limitations

A broad sample from the latest round of the NFHS-4 (2015–16) was used in this analysis to explore the Spatial Heterogeneity in the Coverage of full Immunization among Children in India with particular attention to the contribution of the Immunization Card. Therefore, this study offers up to date population level information on the coverage of childhood immunization in India. Additionally for the first time, we also examined the association between immunization card and coverage of full immunization. This research also has some limitations, as with all observational studies. One limitation is that due to the lack of full data on health services at the district level, we were unable to assess health systems directly. Although the immunization card, urban residence, wealth index, and education are associated with health systems differences, there may be some other systemic variables that we are not able to capture with the data. Second, the analysis used cross-sectional data, which prevents us from understanding the causal relationship between the predictors and the outcome variables.

Conflict of Interest

Authors' declare that the article submitted has not been published previously and is not under consideration for publication elsewhere. Furthermore, the manuscript has approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out. Authors' declare no conflict of Interests.

Ethical approval

Present analysis utilizes a secondary data set with no identifiable information on the survey participants. This dataset is available in public domain for research use. All the survey tools and protocols of different rounds of NFHS has been approved by the Institutional Ethical Review Board of the Institute, where the informed consent have been taken with focus at privacy, confidentiality, voluntary participation and risk reduction. Therefore, no other approval was required for the analysis and publication of this paper.

Consent for Publication

Not Applicable.

Availability of data and material

The data is available online on the website of International Institute for Population Sciences Mumbai. IIPS has been the nodal agency for different rounds of NFHS survey and hence IIPS data center has made NFHS data of different rounds available for the use of the public. Dr. S. K. Singh being the Project Director of NFHS from 1998 to 99 and Ms. D. Vishwakarma being a doctoral student of this institute, have accessed the data from institute's data center.

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Authors' contributions

Dr. S.K. Singh conceived the idea. Ms. D. Vishwakarma designed the experiment and analyzed the data from three rounds of NFHS. Both the authors interpreted the results, drafted the manuscript, reviewed the key findings and finalized he manuscript.

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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