Vaccine Preventable Diseases in Children Following a Nationwide Sanitation Campaign

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Declarations

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4. National Family Health Survey (NFHS-4): International Institute for Population Sciences (IIPS) and ICF. National Family Health Survey (NFHS-4), 2015-16: India. Mumbai: IIPS 2017. URL: https://dhsprogram.com/pubs/pdf/FR339/FR339.pdf

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Abbreviations:

SBM: Swachh Bharat Mission; u5: under 5 years old; VPD: Vaccine Preventable Diseases; DPT: Diphtheria Pertussis Tetanus; HMIS: Health Management Information System; AHS: Annual Health Survey; DLSH: District Level Household and Facility Survey; NFHS: National Family Health Survey.

Abstract

Background: India consistently reports the most diphtheria, pertussis, tetanus and measles cases worldwide. Persistent exposure to fecal pathogens due to open defecation may cause environmental enteropathy that in may lead to undernutrition and vaccine failure in under 5-year old (u5) children. The Swachh Bharat Mission (SBM) program in India, launched in 2014, aimed to construct toilets for every household nationwide and reduce open defecation.

Objective: We examine whether increased household toilet availability in Indian districts corresponds with a reduction in 4 Vaccine Preventable Diseases (VPDs): diphtheria, pertussis, tetanus and measles.

Methods: We retrieved data on district level change in the prevalence (per 1000 u5 children) of 4 VPDs, from 2013 (pre-SBM) to 2016 (post-SBM). We obtained data on our exposure, the change in the percentage of households with toilets (per district), from three large national surveys conducted in 2013 and 2016. We used linear regression analysis which controlled for change over time in socioeconomic factors, health system-related covariates and pre-SBM prevalence of VPDs.

Results: A one percentage point increase in households with toilets corresponds with 0.33 fewer measles cases per 1000 u5 children in that district (coefficient: -0.33, 95% CI: -0.0641, -0.014; $p < 0.05$). We observe no relation with diphtheria, pertussis, or tetanus.

Conclusion: Rapid improvements in ambient sanitation through increased toilet availability (and reduction in open defecation) may correspond with reduction in the prevalence of measles in u5 children.

Key words: Vaccine Preventable Diseases (VPDs); under 5-year children; India, toilets; open defecation; Swachh Bharat Mission

Background

In 2019, India recorded the greatest incidence of diphtheria and tetanus of any country worldwide.(1) India also ranked among the top 10 countries worldwide in pertussis and measles cases.(1) Whereas overall cases for these vaccine preventable diseases (VPDs) declined steadily over the past decade, India's abysmal global ranking raises questions about low vaccine effectiveness despite its over 90% immunization coverage following the initiation of the Universal Immunization Program in 2012.(2) Current immunization programs may require augmentation through separate public health measures that reduce the prevalence of infectious diseases and/or strengthen immune response to vaccines particularly in under 5-year old (u5) children who bear the greatest burden of these illnesses.(3)

Improved sanitation may play a role in strengthening children's immune response.(4) Owing to lack of toilets and the widespread practice of open defecation, India serves as a unique case study for examining the role of improved sanitation on vaccine efficacy and VPD reduction in u5 children.(5,6) As of 2015, over 60% of the global population that practices open defecation lives in India.(5,6) This practice exposes populations to fecal pathogens and imposes a significant negative externality. The prevalence of open defecation in a neighborhood (i.e., sanitation behavior of others in the immediate surroundings) is an ecological exposure that adversely affects child health.(7,8)

Prolonged exposure to fecal pathogens may cause environmental enteropathy, also referred to as tropical enteropathy or jejunitis.(9) This condition, or syndrome, includes nutrient malabsorption in the small intestine, atrophy of intestinal villi, crypt hyperplasia, T-cell infiltration and inflammation of the jejunum.(4,9) Environmental enteropathy may cause undernutrition that, in turn, may lead to immune dysfunction and impairment.(4) Researchers assert that levels of antibodies produced after vaccination are lower among malnourished children and that environmental enteropathy contributes to this phenomenon.(10) Moreover, environmental enteropathy can lead to induction of regulatory T cells which can diminish vaccine-specific responses, or destroy an attenuated vaccine by an aggressive local immune response in the digestive tract.(11,12)

Whereas environmental enteropathy is better characterized with respect to oral vaccine responses(11,12) (e.g., polio and rotavirus), although with mixed evidence(13,14), studies also find an association between enteropathy and diminished parenteral vaccine response through suppressed immunity, altered gut microbiota and undernutrition.(15–17) For instance, research finds lower measles-specific IgG antibody levels in undernourished infants, with higher susceptibility to measles infection despite vaccination.(18) Large sample multi-national analyses also report a positive association between deaths due to measles and undernutrition in children.(19) Environmental exposures and nutrition status may also moderate humoral response to pertussis vaccine.(20) Vaccine responses to diphtheria and tetanus appear attenuated in severely undernourished children but not among those with mild-to-moderate undernutrition.(10)

Encouragingly, rapid improvements in ambient sanitation may reverse environmental enteropathy within a relatively short time span.(21,22) Public health investments in improving sanitation and reducing open defecation, therefore, may serve as a key strategy towards augmenting universal immunization efforts and reducing the burden of VPDs. In October 2014, the Indian federal government launched one of the world's biggest national sanitation programs- the Swachh Bharat Mission (SBM). SBM aims to construct toilets for every Indian household and eliminate the practice of open defecation by 2019.(23) Over this five year period, the SBM program received annual funding of over $1 billion. According to government statistics, over 100 million toilets have been constructed across the country thus far.(23) This program combined financial incentives for toilet construction (at the household level) with intensive behavioral change messaging through multiple channels (community mobilization, social media, radio, television, public service announcements and cinema) that promoted toilet utilization and sanitary behaviors. Between late 2014 and early 2019, the Indian population was exposed to about 2,500-3,300 SBM-related messages per capita, amounting to, on average, 11 sanitation-related behavior change messages per person per week (Dalberg WASH Institute, 2019).(24) Whereas India has implemented other sanitation policies in the decades preceding SBM, none of the prior programs combined public awareness campaigns with toilet construction on the scale of SBM.(25)

Recent work suggests that increased toilet availability following the SBM program may have reduced child undernutrition(26) and diarrheal outbreaks(27) in India. However, we know of no work that examines whether these improvements extend to reduced VPD prevalence among u5 Indian children. We leverage the quasi-random nature of the SBM program to examine whether large increases in toilet availability correspond with reductions in each of four VPDs in u5 children- diphtheria, pertussis, tetanus and measles. We examine 532 districts in India and analyze whether a change in household-level toilet availability, pre- and post-SBM (2013 and 2016 respectively) varies inversely with VPD prevalence over time. Our district-level ecological analysis, conducted for almost all Indian states, may hold key implications for public health and policy with respect to understanding whether sanitation improvements have the potential to reduce the high burden of child mortality from VPDs.

Methods

Data and variables

Starting in 2012, the Government of India's National Health Mission publishes annual district level data on the prevalence of VPDs among u5 children through a Health Management Information System (HMIS) portal.(28) While its relative novelty has precluded it from wide use, recent literature acknowledges the superiority of HMIS data over previously existing databases on immunization and VPDs in India.(29,30) The HMIS reports annual district-level information on immunization, adverse events and prevalence of diphtheria, pertussis, tetanus, measles and other illnesses among u5 children.(28) These data serve as a central repository of VPD surveillance across India and undergo several rounds of validation checks at village, sub-center, block, district and state-levels.(31) HMIS data files are publicly available.(28) We used these data to retrieve information on our outcomes of interest: the change in prevalence of (a) diphtheria (b) pertussis (c) tetanus and (d) measles per 1000 under-5 year old (u5) children, per district, from 2013 (pre-SBM) to 2016 (post-SBM), for all Indian districts.

We retrieved data on our exposure (district-level change from 2013 to 2016 in percentage of households with toilets) from three national survey datasets. These three datasets comprise (a) District Level Household & Facility Survey, round 4 (DLHS-4), (b) Annual Health Survey (AHS, second update) and (c) National Family Health Survey, round 4 (NFHS-4). DLHS 4 is a nationwide survey sponsored by the Ministry of Health and Family Welfare and covers 21 states and union territories (321 districts) with 1000 to 1500 households sampled under each district.(32) AHS is sponsored by the Office of the Registrar General, India, on behalf of the Ministry of Health & Family Welfare for 9 high-risk states that have traditionally fared the worst in terms of child health indicators in India.(33) AHS covers 284 districts with an average of 12,000 households sampled per district.(33) The DLHS-4 and AHS datasets report information for 2013 (pre-SBM). The National Family Health survey is a decennial survey in India administered through the Demographic Health Surveys Program and its fourth round (NFHS-4) reports data for 2016 (post-SBM).(34) Its sample size is approximately 572,000 households, in 640 districts across all 29 states and 9 union territories in India.(34) NFHS-4, unlike its predecessor (NFHS-3), contains sub-state geographic identifiers, permitting the use of districts as the unit of analysis.(34) Households surveyed in DLHS-4, AHS and NFHS-4 are sampled to be representative (in aggregate) at the district level and have been utilized extensively in pooled longitudinal format.(35,36) According to an analysis by the World Health Organization, these datasets have been used in over 600 scientific publications, in addition to extensive utilization by the World Bank, Government of India and other policy making agencies.(37)

HMIS data report the relative percentage of VPDs to total reported childhood diseases (per district, per year). We converted these ratios to absolute prevalence (per 1000 u5 children per district-year) using the number of u5 children reporting any illness from AHS, DLHS-4 and NFHS-4. Using these survey datasets, we also calculated the number of households reporting use of unshared (i.e., personal) toilets as a percentage of total number of surveyed households per district in 2013 and 2016. We defined our exposure as the difference in district-level percentage of households with toilets in 2016 relative to 2013. We also obtained a set of control variables from the DLHS-4, AHS and NFHS-4 datasets to account for factors that may have changed from 2013 to 2016 and that might be associated with changes in VPD prevalence. These variables include change in percentage of households with electricity, percentage of households with clean drinking water (boiled and/or treated), percentage of households with clean cooking fuel (liquefied petroleum gas and/or biogas), percentage of women with 10th grade or higher education, percentage of child births in hospitals (institutional deliveries), percentage of ≤ 1year old children who received diphtheria-pertussis-tetanus (DPT) vaccine and percentage of ≤ 1year-old children who received the measles vaccine. A large literature describes the role of these variables in determining child health outcomes in developing countries.(38) Their inclusion reduces confounding by general improvements in district-level health systems and socioeconomic attributes that may co-occur with implementation of the SBM program over the study period. Our final analytic file containing districts reported uniformly across all datasets (HMIS, DLHS-4/AHS, NFHS-4) comprised 532 districts as the units of analysis. Gujarat, Jammu & Kashmir and a few Union Territories were excluded as they were not covered in the pre-SBM survey datasets (AHS, DLHS-4)

Analysis

We specified the following test equation:

$$\Delta \mathrm{Y} = \beta_0 + \beta_1 \Delta \text{Percentage of households with toilets} + \beta_2 \text{Baseline VPD prevalence} + \boldsymbol{\beta}' \boldsymbol{\Delta}\textbf{Controls} + \varepsilon \qquad \textbf{-Equation 1}$$

where

ΔY is the change in VPD prevalence (2016 minus 2013) per 1000 u5 children per district, examined separately by VPD type (Diphtheria, Pertussis, Tetanus, Measles)

ΔPercentage of households with toilets is the change in percentage of households with toilets (2016 minus 2013) per district. β_1 serves as the main coefficient of interest.

Baseline VPD prevalence is the pre-SBM (i.e., 2013) prevalence of respective VPD per 1000 u5 children.

$\mathbf{\Delta Controls}$ is the vector of control variables (2016 minus 2013) listed earlier.

ε is the heteroscedasticity-robust standard error term.

We utilized Ordinary Least Squares (OLS) regression analysis to estimate Equation 1 separately for each VPD. For tests that rejected the null, we stratified Equation 1 by India's administrative regions (central, eastern, northern, north eastern, southern and western) to explore which regions show the greatest change in outcome per increase in exposure. In addition, for any results in which rejected the null, we then reformulated the outcome as change in counts (as opposed to per 1000 prevalence) of VPDs in u5 children per district to obtain the average marginal effect of change in exposure on the outcome (case counts). For all analyses, we specified robust standard errors to account for correlated errors. We conducted all analyses in Stata SE version 14.2.(39)

Results

Table 1 describes the mean and standard deviation of the covariates included in our study by pre- and post-SBM, as well as the change over this period. The prevalence of VPDs in u5 children (per 1000) declines from 2013 to 2016. Measles shows the greatest reduction, followed by diphtheria, pertussis and tetanus. These trends align with India's national surveillance data reported by the World Health Organization.(40) Mean percentage of households with toilets per district increases from 45% in 2013 to 53% in 2016, which agrees with other reports.(41) Appendix Table 1 describes the distribution of outcome variables (mean) at various percentiles. Most districts (from the 25th to 95th percentile) report no change from 2013 to 2016 in diphtheria, pertussis and tetanus, except at the lowest (1st to 10th) and highest (95th to 99th) percentiles of change. The distribution of change in prevalence of measles (per 1000 u5 children) over time is relatively more uniform across all percentiles of change.

Figure 1 maps the district-level change in VPDs (2016 minus 2013) across India. Sections of Gujarat, Jammu & Kashmir, Bihar, Maharashtra, Madhya Pradesh and Telangana show reduction in diphtheria (Figure 1, Panel A). Prevalence of pertussis does not change in most regions, except for some areas in Rajasthan, Bihar, Kerala and a few other districts (Figure 1, Panel B). Tetanus in u5 children declines in some parts of northern and central India, with most regions showing no change (Figure 1, Panel C). The prevalence of measles shows substantial decline across almost all Indian states (except Rajasthan and Maharashtra), with Madhya Pradesh, Chhattisgarh, Bihar, Odisha and Karnataka showing near-universal decline in all districts within these states.

Figure 2 maps the change in district-level percentage of households with toilets across India. We observe a near-uniform increase in household-level toilet availability nation-wide. The most visible improvements occur in Rajasthan, Himachal Pradesh, Chhattisgarh, Assam and Odisha.

We observe no relation between increase in percentage of households with toilets and change in the prevalence of Diphtheria, Pertussis and Tetanus per 1000 u5 children (Table 2, Models 1, 2, 3). However, for every one percent increase in exposure, the prevalence of measles in u5 children (per 1000) declines by 0.33 units (coefficient = -0.33, 95% CI: -0.641, -0.014, $p < 0.05$) (Table 2, Model 4). This decline concentrates in central and north eastern Indian districts (Appendix Table A.2), presumably owing to greater change in percentage of households with toilets in these two regions (Appendix Table A.3). Examination of change in counts (rather than prevalence per 1000 u5 children) of u5 measles cases indicates 0.16 fewer cases for every one percentage point increase in exposure. Put another way, for a 7% increase in households with toilets (i.e., mean change reported in Table 1), our analyses suggest 1.12 fewer cases of measles in u5 children per district, on average, over our study period (Appendix Figure A.1).

Discussion

Open defecation exposes populations to fecal matter pathogens and may cause environmental enteropathy. This enteropathy may interfere with immune functioning and vaccine response in children.(4,9) India reports the greatest prevalence globally of open defecation stemming from lack of toilet availability and usage.(6) The Swachh Bharat Mission (SBM) program, launched in 2014 by the Government of India, aimed to eliminate open defecation through intensive behavioral change messaging and construction of over 100 million toilets nationwide.(23) We examined whether and to what extent increase in toilet availability varied inversely with four Vaccine Preventable Diseases, namely, diphtheria, pertussis, tetanus and measles, in u5 children. We find that an increase in percentage of households with toilets is associated with a modest reduction in measles, but not in diphtheria, pertussis or tetanus. Findings provide proof-of-concept that improvements in ambient sanitation may augment universal immunization efforts in reducing the burden of measles among u5 children in India.

Strengths of this study include the utilization of precise timing of an exogenously determined public sanitation program (SBM), which lends a quasi-experimental design to our analysis. We also view the brief time lag post-SBM initiation as a strength of the study design. Use of a shorter time lag minimizes the risk of confounding due to the plausible rival of "maturation" in which a variety of infrastructure improvements, and cultural changes, which follow SBM but are not caused by SBM, improve child health overall. Maturation, for instance, would tend to threaten validity had we extended the time-horizon to several years post-intervention.(42)

In addition, we use large, nationally representative data sources that permit analysis of VPDs in u5 children with respect to open defecation—a district-level exposure that carries a high negative externality. Furthermore, all datasets used in this study are publicly available which permits replication. We also minimize confounding by specifying in our analysis several key variables that are widely recognized as strong correlates of child health outcomes. Lastly, we account for baseline differences across districts in the prevalence of VPDs, which reduces the threat of regression to the mean over the study period.

One limitations of our study is that we do not examine the relation between VPD and toilets by rural or urban regions. Prior research reports that child health may vary by population density of open defecation and by toilet availability within districts.(7,43) The HMIS data, however, do not report VPD prevalence by rural/urban divisions within districts and hence limit detailed analyses by within-district regions. Owing to data limitations, we also cannot examine differential responses by gender or age groups.(26) Whereas current HMIS data remain limited to aggregate district-level reporting, we encourage future research to extend our analyses and examine these subgroups following availability of detailed VPD surveillance datasets in India.

Our analyses indicate a decline in prevalence of measles in u5 children following increased toilet availability, but no changes in the prevalence of diphtheria, pertussis and tetanus. We offer three *post hoc* explanations for this observation. First, vaccine response to measles relies on vitamin A supplementation and absorption.(44) Vitamin A supplementation increased from 54% in 2013 to 71% in 2016 among u5 children in India.(45) This increase, combined with increased toilet availability (and potential reduction in environmental enteropathy) in some districts may correspond with improved absorption of Vitamin A in u5 children. Second, the highly contagious nature of measles (relative to diphtheria, pertussis and tetanus) may impart greater amenability to change, following SBM. Third, diagnosis of measles often carries lower ambiguity (owing to distinct rash) relative to diphtheria or pertussis (which commonly present with cough and/or fever), which may correspond with under-diagnosis and under-reporting of the latter.(46–48) This low reporting may have precluded us from detecting the "true" magnitude of cases averted by SBM, even if a true relation between SBM and lower diphtheria, pertussis and tetanus cases actually occurred. However, to the extent that detection remains consistent within a particular district over time, our statistical models render data comparable between time points by utilizing the *difference* in VPD rates rather than absolute magnitude at each time point.

In 2019, India introduced an indigenously produced rotavirus vaccine into its Universal Immunization Program.(49,50) Rotavirus infections in u5 children account for nearly 40% of diarrheal episodes in India.(51) Repeated diarrheal infections further exacerbate pre-existing environmental enteropathy, undernutrition and vaccine failure.(4,9) The introduction and expansion of the rotavirus vaccine, in combination with improved sanitation following SBM, may confer substantial benefits to vaccine response and improved nutrition among Indian children. Whereas we do not know of any nationally representative, publicly available data sets that report annual district-level rotavirus surveillance in u5 children, we encourage policy makers to provide this information for future research and evaluation.

Biological markers of environmental enteropathy offer clinically definitive methods to identify the extent and severity of this condition and subsequent evaluation of physiological changes following improved ambient sanitation.(17) Intestinal biopsies conducted in the 1960s, such as those by Lindebaum and colleagues., may not serve as feasible means for identification of enteropathy in current epidemiological studies.(22) Recent research identifies malabsorption, changes in local immune activity and intestinal permeability as key diagnostic features of environmental enteropathy.(17) Measurement of biomarkers of carbohydrate malabsorption (e.g., lactulose-mannitol), mucosal activity (e.g., T-helper cell type 1), serum protein from intestinal mucosa and markers of systemic immune activity and inflammation (e.g., C-Reactive Protein, glycoproteins) may provide direct evidence of environmental enteropathy.(17) Such analyses may augment ecological research, such as ours, in understanding clinical as well as epidemiological ramifications of improved sanitation on child health.

Conclusion

Improvements in ambient sanitation through construction and utilization of toilets may augment current efforts in reducing the burden of Vaccine Preventable Diseases among children in India and other low and middle income countries.

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Table 1: Mean and Standard Deviation (SD) of variables Pre-SBM (in 2013), Post-SBM (in 2016) and change over time (Post SBM minus Pre SBM) across 532 districts (28 states) in India

Variables	**Pre-SBM (2013)**		**Post SBM (2016)**		**Change (Post SBM - Pre SBM)**	
	Mean	SD	Mean	SD	Mean	SD
Diphtheria per 1000 u5 children	2.13	12.56	0.60	3.87	-1.54	13.11
Pertussis per 1000 u5 children	0.93	6.49	0.18	1.70	-0.77	6.74
Tetanus per 1000 u5 children	0.63	4.29	0.18	1.42	-0.42	4.56
Measles per 1000 u5 children	23.87	35.96	18.23	30.07	-5.12	39.22
Percentage of households with toilets	45.33	25.77	52.25	24.53	6.55	9.99
Percentage of households with electricity	69.02	32.09	88.02	14.72	18.59	20.53
Percentage of households with clean drinking water	21.64	24.86	26.88	26.18	5.31	8.45
Percentage of households with clean cooking fuel	30.07	23.80	37.69	23.24	7.33	10.67
Percentage of women with 10^{th} grade or higher education	26.70	15.85	34.44	14.40	7.80	7.54
Percentage of ≤ 1 year old children with DPT vaccination	77.24	12.82	78.34	14.80	0.95	14.27
Percentage of ≤ 1 year old children with measles vaccination	79.86	13.65	80.64	13.33	0.63	11.68
Percentage of births in hospitals	74.25	20.52	78.90	17.32	4.51	9.25

Figure 1: District-level maps of India showing change in diphtheria (Panel A), pertussis (Panel B), tetanus (Panel C) and measles (Panel D), from 2013 to 2016.

Source: India shapefiles were obtained from publicly available GitHub repository: https://github.com/datameet/maps/find/master. Maps in manuscript have been created by authors.

Figure 2: District-level map of change in percentage of household with toilets in India (2013 to 2016)

Source: India shapefiles were obtained from publicly available GitHub repository: https://github.com/datameet/maps/find/master. Maps in manuscript have been created by authors.

Table 2: Linear regression predicting Change in VPDs (Vaccine Preventable Diseases) as a function of Change in percentage of households with toilets, controlling for change in other covariates and baseline (pre-SBM) prevalence of VPDs (N = 532).

	Model 1			Model 2			Model 3			Model 4		
Covariates	Outcome: change in Diphtheria per 1000 u5 children			Outcome: change in Pertussis per 1000 u5 children			Outcome: change in Tetanus per 1000 u5 children			Outcome: change in Measles per 1000 u5 children		
	Coefficient	95% CI		Coefficient	95% CI		Coefficient	95% CI		Coefficient	95% CI	
Change in percentage of households with toilets	0.006	[-0.026	0.039]	-0.007	[-0.020	0.006]	-0.000	[-0.021	0.020]	**-0.328***	[-0.641	-0.014]
Change in percentage of households with electricity	0.009	[-0.014	0.033]	-0.006	[-0.014	0.001]	-0.001	[-0.010	0.007]	0.144	[-0.013	0.302]
Change in percentage of households with clean drinking water	-0.011	[-0.030	0.008]	0.003	[-0.012	0.018]	-0.009	[-0.021	0.004]	-0.161	[-0.389	0.066]
Change in percentage of households with clean cooking fuel	0.013	[-0.009	0.034]	0.005	[-0.006	0.017]	-0.011	[-0.025	0.002]	-0.127	[-0.369	0.114]
Change in percentage of women with 10^{th} grade or higher education	0.012	[-0.023	0.046]	0.015	[-0.014	0.043]	0.010	[-0.006	0.026]	0.432	[-0.078	0.941]
Change in percentage of ≤ 1 year old children with DPT vaccination	-0.004	[-0.024	0.015]	0.004	[-0.002	0.010]	-0.015	[-0.035	0.005]	--	--	--
Change in percentage of ≤ 1 year old children with measles vaccination	--	--	--	--	--	--	--	--	--	-0.128	[-0.326	0.070]
Change in percentage of births in hospitals	0.005	[-0.022	0.031]	-0.011	[-0.024	0.002]	0.008	[-0.015	0.032]	0.166	[-0.115	0.447]
Baseline (pre-SBM) Diphtheria per 1000 u5 children	-0.997***	[-1.020	-0.975]	--	--	--	--	--	--	--	--	--
Baseline (pre-SBM) Pertussis per 1000 u5 children	--	--	--	-0.999***	[-1.003	-0.996]	--	--	--	--	--	--
Baseline (pre-SBM) Tetanus per 1000 u5 children	--	--	--	--	--	--	-1.001***	[-1.006	-0.996]	--	--	--
Baseline (pre-SBM) Measles per 1000 u5 children	--	--	--	--	--	--	--	--	--	-0.767***	[-0.897	-0.638]

* p<0.05, ** p<0.01, *** p<0.001

Appendix

Appendix Table A.1: Distribution of mean of change in VPDs (Diphtheria, Pertussis, Tetanus, Measles) per 1000 u5 children by 5-unit increments of their respective percentile distributions (532 districts in India, change estimated as the difference between year 2016 and year 2013 values)

Percentile	Diphtheria	Pertussis	Tetanus	Measles
1st	-42.6	-25.5	-12.6	-165.8
5th	-6.6	-3.1	-2.2	-65.3
10th	-2.3	-0.8	-0.5	-33.2
25th	0	0	0	-13.6
50th	0	0	0	-0.1
75th	0	0	0	4.5
90th	0	0	0	20.8
95th	1.1	0	0.1	43.9
99th	14.4	3.1	5.3	135

Appendix Table A.2: Linear regression predicting Change in Measles as a function of Change in percentage of households with toilets, controlling for change in other covariates and baseline (pre-SBM) prevalence of measles, by 6 administrative regions of India.

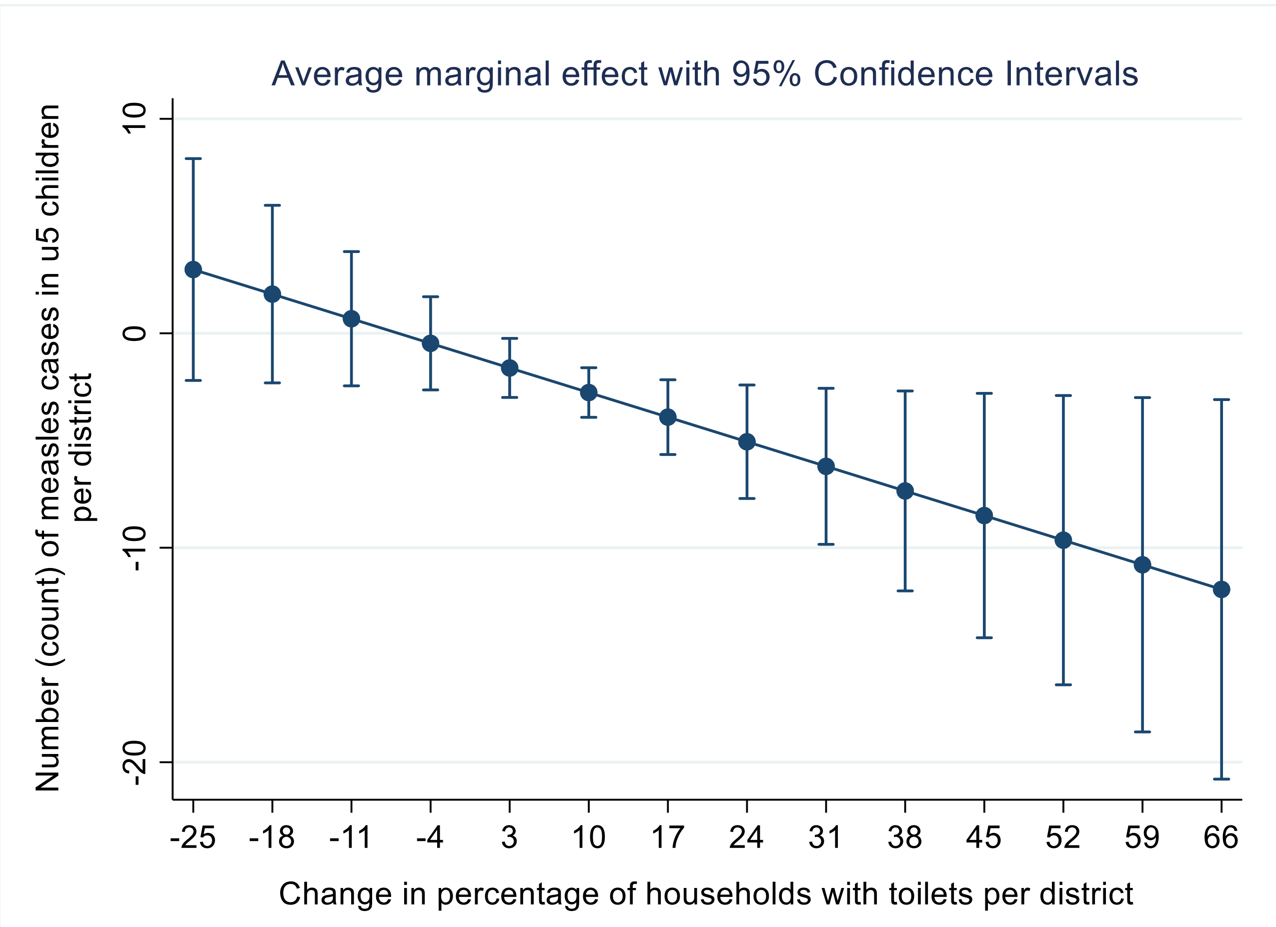
Covariates	Central		Eastern		North Eastern		Northern		Southern		Western	
	Coefficient	95% CI	Coefficient	95% CI	Coefficient	95% CI	Coefficient	95% CI	Coefficient	95% CI	Coefficient	95% CI
Change in percentage of households with toilets	**-1.223***	[-2.390 -0.057]	0.006	[-0.503 0.515]	**-0.475***	[-0.882 -0.068]	0.331	[-0.226 0.887]	-0.317	[-0.992 0.357]	0.202	[-0.544 0.949]
Change in percentage of households with electricity	0.526	[-0.067 1.119]	-0.300*	[-0.572 -0.029]	-0.032	[-0.452 0.388]	-0.150	[-0.617 0.317]	0.612	[-1.432 2.656]	-0.268	[-2.041 1.505]
Change in percentage of households with clean drinking water	-0.428	[-2.107 1.250]	0.381	[-0.122 0.884]	0.275	[-0.401 0.951]	-0.270	[-0.812 0.271]	-0.095	[-0.415 0.224]	-0.636	[-1.352 0.081]
Change in percentage of households with clean cooking fuel	0.545	[-0.303 1.393]	-1.094*	[-2.042 -0.146]	-0.216	[-0.892 0.459]	-0.113	[-0.469 0.242]	-0.220	[-0.492 0.052]	-0.162	[-0.735 0.410]
Change in percentage of women with 10^{th} grade or higher education	3.006**	[0.762 5.250]	1.834	[-0.657 4.325]	-0.252	[-1.100 0.595]	-0.127	[-1.143 0.889]	-0.329	[-0.818 0.160]	0.732	[-0.226 1.690]
Change in percentage of ≤ 1 year old children with measles vaccination	-0.233	[-1.039 0.573]	0.238	[-0.363 0.838]	-0.223	[-0.523 0.078]	-0.131	[-0.439 0.176]	0.311*	[0.012 0.610]	-0.350	[-1.409 0.709]
Change in percentage of births in hospitals	-0.087	[-0.740 0.565]	0.814*	[0.033 1.595]	0.205	[-0.239 0.648]	-0.312	[-0.929 0.305]	0.264	[-0.479 1.007]	0.254	[-0.936 1.444]
Baseline (pre-SBM) Measles per 1000 u5 children	-0.967***	[-1.156 -0.778]	-0.798***	[-0.910 -0.685]	-0.291	[-0.629 0.048]	-0.449	[-1.145 0.247]	-0.736***	[-0.975 -0.496]	-0.810***	[-1.161 -0.459]
N	121		107		80		85		103		36	

* p<0.05, ** p<0.01, *** p<0.001

Appendix Table A.3: Mean of change in (1) measles per 1000 u5 children and (2) percentage of households with toilets, by India's administrative regions.

Region	Mean change in measles per 1000 u5 children	Mean change in %age of households with toilets
central	-7.44	7.97
eastern	-14.68	5.50
north eastern	-0.60	9.93
northern	-0.96	7.76
southern	-3.91	4.23
western	5.80	0.57

Appendix Figure A.1: Average marginal effect (with 95% Confidence Intervals) of change in percentage of household with toilets on counts of u5 measles cases per district in India



Figures

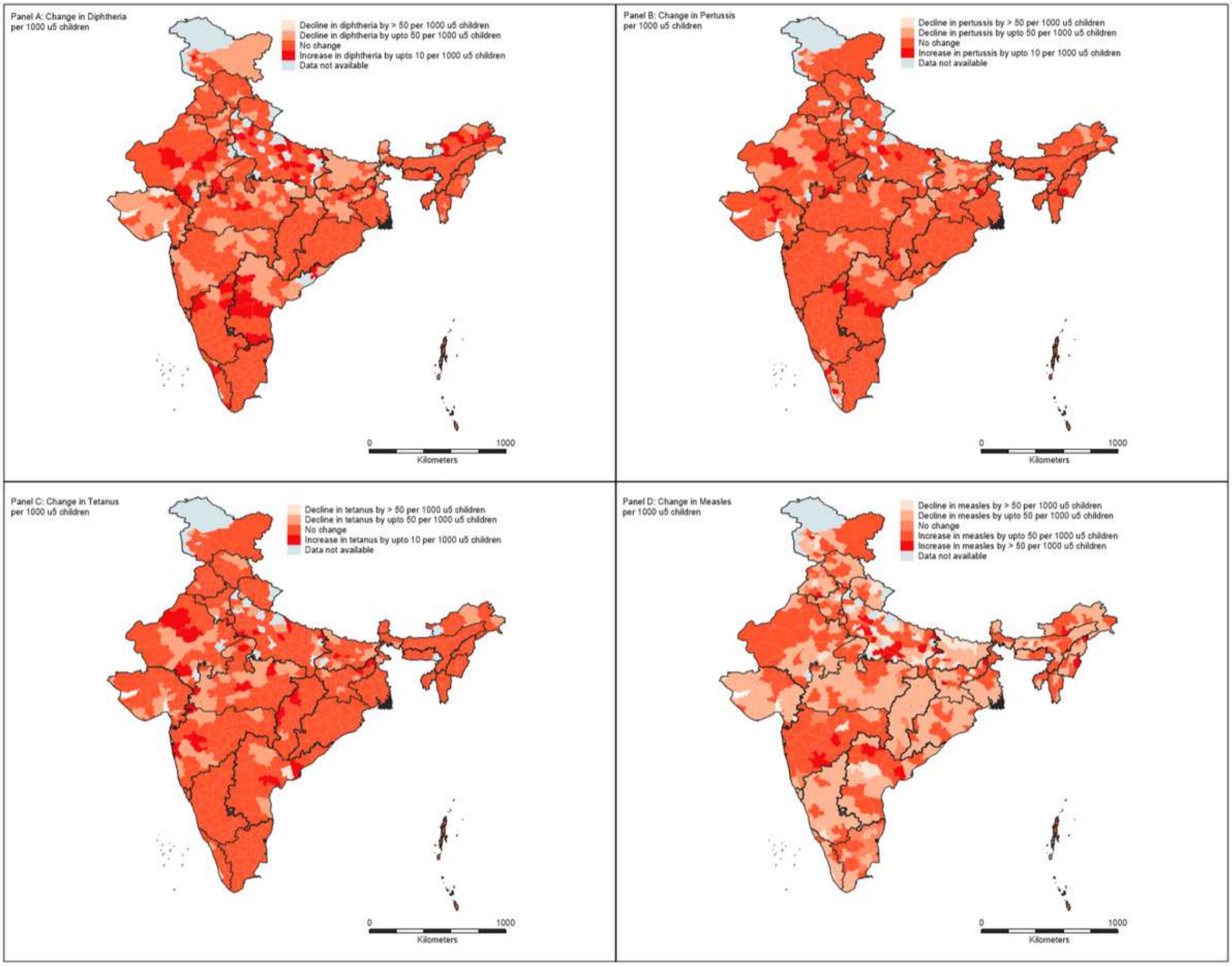


Figure 1

District-level maps of India showing change in diphtheria (Panel A), pertussis (Panel B), tetanus (Panel C) and measles (Panel D), from 2013 to 2016. Source: India shapefiles were obtained from publicly available GitHub repository: https://github.com/datameet/maps/find/master. Maps in manuscript have been created by authors.

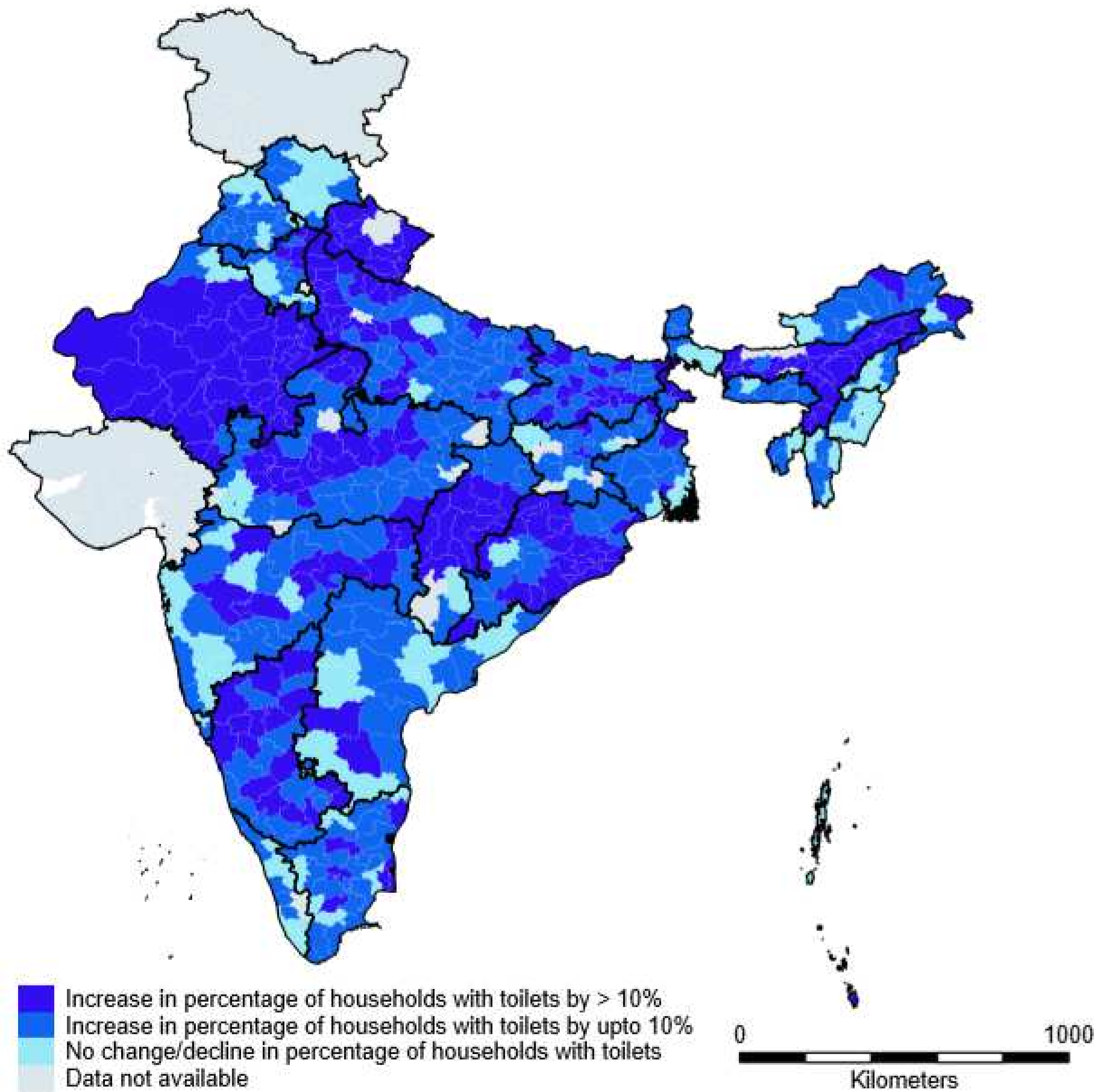


Figure 2

District-level map of change in percentage of household with toilets in India (2013 to 2016) Source: India shapefiles were obtained from publicly available GitHub repository: https://github.com/datameet/maps/find/master. Maps in manuscript have been created by authors.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementarymaterialAppendix.docx