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Child Undernutrition following the Introduction of a Large-Scale Toilet Construction Campaign in India

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ABSTRACT

Background: Lack of toilets and the widespread practice of open defecation may contribute to India's large burden of child undernutrition.

Objectives: We examine whether a large national sanitation campaign launched in 2014, the Swachh Bharat Mission (SBM), precedes a reduction in stunting and wasting among under 5-y-old (u5) children in India.

Methods: In this observational study, we used district-level data from before (2013–2014) and after (2015–2016) SBM from 3 national surveys to derive, as our outcomes, the percentage of u5 children per district who are stunted and wasted. We defined our exposures as *1*) binary indicator of SBM and *2*) percentage of households with toilets per district. Our analytic sample comprised nearly all 640 Indian districts (with ∼1200 rural/urban divisions per district per time point). Linear regression analyses controlled for baseline differences in districts, linear time trends by state, and relevant covariates.

Results: Relative to pre-SBM, u5 stunting declines by 0.06% (95% CI: –0.10, –0.01; $P = 0.009$) with every percentage increase in households with toilets post-SBM. Rural regions and districts with higher pre-SBM toilet availability show greater decline in u5 stunting post-SBM.

Conclusions: An increase in toilet availability on a national scale, precipitated by the SBM sanitation campaign, is associated with a reduction in undernutrition among u5 children in India over the early phase of the campaign. *J Nutr* 2021;151:2455–2464.

Keywords: open defecation, sanitation, child stunting, India, Swachh Bharat Mission

Introduction

India accounts for nearly one-third of the global burden of undernutrition in under 5-y-old (u5) children (1). Stunting (height for age below –2 standard deviations relative to global reference curves) and wasting (weight for height below –2 standard deviations relative to global reference curves) remain alarmingly high among Indian children relative to other countries of similar national economic output (2, 3). This phenomenon, often referred to as the "Asian enigma," may arise from the extensive practice of open defecation in India (4). Absence of household toilets and low utilization of toilets promote open defecation and contaminate ambient environment and water sources with fecal pathogens. In 2012, nearly half of India's 1.2 billion people reported lack of household toilets and practiced open defecation (5). This indiscriminately strewn human waste serves as one of the most lethal and rampant means for spreading disease.

Open defecation carries a significant negative externality. Persistent exposure to high concentrations of fecal matter elevates the incidence of infections reliant on the fecal-oral route of transmission, particularly among young children (6). Repeated infections of the gut may induce subclinical permeability changes in the small intestine, also referred to as environmental enteropathy. This condition causes malabsorption of nutrients, resulting in chronic undernutrition and stunting (6, 7). Undernutrition among u5 children may "program" future growth (8–11). Sanitation efforts to reduce open defecation may reduce child undernutrition, particularly among u5 children (2). High population density, moreover, may exacerbate the potential effects of open defecation on child health. Improved sanitation may, therefore, hold particular relevance for India (12).

Intriguingly, recent multinational randomized controlled trials in low- and middle-income countries (LMICs) have not found a relation between open defecation (low toilet use) and growth faltering among children (13–18). Scholars contend that the absence of this relation may arise from low baseline prevalence of open defecation in these countries, which limits

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their generalizability to India (18–22). In India, studies present mixed findings. Cross-sectional studies report a positive relation between open defecation (or lack of toilet availability) and child stunting (5, 23). Small-scale randomized controlled trials in India show that provision of toilets and behavioral change messaging increase toilet construction, reduce open defecation, and increase child height (24). Moreover, these height gains in u5 children appear within a relatively short time span (24). Research examining India and 3 other LMICs (Ethiopia, Peru, Vietnam) also finds that stunting among children corresponds inversely with access to toilets (except for Vietnam) (25). However, several cluster-randomized controlled trials in Indian villages have found no benefit of toilet access to child health (26, 27). The authors attribute these null results to inconsistent usage of toilets and lack of effective behavioral change interventions (26–28). Longitudinal research examining subnational changes in water and sanitation across 59 countries also reports no changes in child stunting or wasting following sanitation improvements, although a reduction in diarrhea and child mortality has been observed (29). These findings suggest that, absent toilet adoption and usage, increased toilet availability alone may not translate into reduced open defecation and improved child nutrition in India (28, 30–32).

In 2014, the election of Prime Minister Narendra Modi's government ushered in the Swachh Bharat Mission (SBM) (33). SBM succeeded the former Nirmal Bharat Abhiyan and put forth a national mandate for total sanitation and complete eradication of open defecation by 2019 (33). The government allotted over $1 billion annually toward this program (33). SBM Gramin (SBM-G) is the flagship component of SBM and focuses on total sanitation in rural India under the Department of Drinking Water and Sanitation (33). SBM Urban (SBM-U) focuses on cities and urban clusters and is implemented by India's Ministry of Housing and Urban Affairs (34). Under SBM-G, rural households are incentivized with a cash subsidy of INR 12,000 (US$170) for toilet construction coupled with intense public messaging (33).

From 2015 to 2020, >100 million household toilets have been constructed in India and >600,000 villages have been declared free of open defecation (33). This national intervention combines toilet construction, waste management, and intensive public messaging, with nearly 10% of all SBM expenditure dedicated to information, education, and communication (IEC) campaigns using a wide variety of channels (social media, cinema, community mobilization, etc.) (33, 35, 36). According to some estimates, the Indian population was exposed to ∼11 sanitation, handwashing, and hygiene-related messages per person per week, sponsored by SBM (35). Studies report, following SBM, a heterogeneous decline in open defecation and increased hygiene awareness in select North Indian states (37, 38). Whereas multiple sources document greater administrative focus and investments made toward IEC and community mobilization toward total sanitation (36, 39), evidence on the large-scale impact of SBM on child health outcomes remains limited.

According to an evaluation in the states of Bihar, West Bengal, and Odisha, villages declared as open defecation free (ODF) following SBM showed marked reduction in fecal contamination relative to non-ODF villages (40). Another study that used data from the Performance Monitoring and Accountability 2020 survey reports, following SBM, a 60% reduction in open defecation among rural and 46% reduction among urban regions of Rajasthan (37). In rural Punjab, a cluster-randomized controlled trial reports a 7% reduction in open defecation, corresponding to ∼6% to 10% increase in toilet ownership following SBM (38). These estimates align with qualitative evidence from other independent evaluations that also report increased toilet adoption in rural North Indian states, owing to increased toilet construction and community and governmental coercion toward use of toilets following SBM (41). We, however, know of only 2 studies that report nationwide evaluations of SBM; neither examine child undernutrition and stunting (42, 43).

SBM represents one of the largest-scale public health campaigns in the second most populous country in the world. For this reason, quantifying the importance of SBM in reducing child undernutrition holds strong policy relevance. Major critiques of Indian sanitation policies that preceded SBM involved nonutilization of constructed toilets and no discernible improvement in child health despite an increase in toilet availability (27, 44). Experts contend that the Total Sanitation Campaign, for instance, failed to mobilize communities and did not emphasize IEC in high-burden states (45). Following SBM, if many newly constructed toilets are now being used, it remains to be seen whether child undernutrition, particularly among u5 children, improves accordingly. We examine, in a longitudinal manner, whether and to what extent an increase in district-level household toilet availability correlates with reductions in percentage of u5 children who are stunted and wasted across all districts in India over the early (i.e., within first 2 y) phase of SBM. The pace of toilet construction and SBM adoption shows considerable variation across Indian states and districts (46). We exploit this geographic variation in the intensity of toilet construction and estimate the relation between SBM-related changes in toilet availability and u5 undernutrition.

Methods

Data sources

We used 3 different publicly available population-level survey data sets in India for our study: *1*) District Level Household and Facilities Survey (DLHS), Round 4 (2013) (47); *2*) Annual Health Survey (AHS, 2013–2014) (48); and *3*) National Family Health Survey (NFHS), Round 4 (2015–2016) (49). These surveys are representative at the district and state levels (47–49). AHS includes 9 "high-burden" Indian states (Uttar Pradesh, Chhattisgarh, Madhya Pradesh, Uttarakhand, Jharkhand, Orissa, Bihar, Assam, and Rajasthan), and DLHS covers the remaining 21 Indian states/territories for the pre-SBM time period of 2013–2014 (except Gujarat and Jammu and Kashmir). NFHS covers all states/territories over the post-SBM time period (2015–2016). Recent studies have used combinations of these data sets to study cross-sectional and longitudinal changes in health outcomes in India (50, 51). The DLHS, AHS, and NFHS data series have been used in >600 scientific publications, in addition to usage by the World Bank, Government of India, and other policy-making agencies (52). This study

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Abbreviations used: AHS, Annual Health Survey; DLHS, District Level Household and Facility Survey; HAD, height-for-age difference; IYCF, infant and young child feeding; IEC, information, education, and communication; LMIC, low- and middle-income country; NFHS, National Family Health Survey; ODF, open defecation free; SBM, Swachh Bharat Mission; SBM-G, Swachh Bharat Mission Gramin; SBM-U, Swachh Bharat Mission Urban; u5, under 5 y old.

used publicly available secondary data and was institutional review board exempt.

Variables

We examined the health outcomes of stunting and wasting among u5 children—2 measures of child undernutrition that may respond to district-level reductions in open defecation. Stunting reflects chronic undernutrition and indicates early, sustained exposure to infections and inadequate diet (53). Wasting reflects acute undernutrition from recent loss in body mass usually following acute starvation and/or severe disease (53). We used child anthropometric measurements (age in months, height in centimeters, weight in kilograms) to construct height-for-age and weight-for-height *z* scores relative to WHO global reference curves for u5 children (54). Next, consistent with the global practice, we classified children at or below −2 SD of height-for-age *z* scores as stunted and below −2 SD of weight-for-height *z* score as wasted (54). We categorized children below −3 SD for these *z* scores as severely stunted and wasted (respectively) (54). We aggregated the number of stunted and wasted children by district (separately for rural/urban areas, classified based on Indian census definitions) (55) to obtain the prevalence of each undernutrition type. We used the total number of u5 children surveyed as the denominator and applied analytic survey weights to render the population-representative estimates at the district level.

We used 2 exposures that measure the timing and intensity of SBM. We first used a binary (1/0) indicator variable of SBM, coded as "0" before SBM implementation (2013–2014) and "1" post-SBM implementation (2015–2016). Next, we used the percentage of households in a district with individual, unshared toilets[1] (total households surveyed as denominator, weighted using survey weights). Given the timing, large magnitude, and broad scope of the SBM campaign, we reasoned that any acute increase from 2013–2014 to 2015–2016 at the district level in having a toilet potentially arises from SBM. We view this assumption as reasonable because, following the launch of SBM, financial allocations for sanitation increased by an unprecedented 24% in the financial year 2014–2015 relative to the financial year of 2013–2014 (56). Indian parliamentary reports indicate that of the 107 million toilets constructed under SBM (until 2020), ~40% (40,520,686) were constructed by 2016 (57). Nationwide toilet availability also increased dramatically after 2014 (58).

Our final analytic sample (excluding districts with missing data) comprised 1127 district-units pre-SBM (563 rural, 564 urban) and 1264 district-units post-SBM (627 rural, 637 urban). To give the reader a sense of the geographic variation of our exposure and outcome variables, we mapped, across all available districts in India, u5 stunting and availability of household toilets by pre- and post-SBM period. We also graphed the unadjusted linear relation between u5 stunting, wasting, and percentage of households with personal toilets for pre- and post-SBM periods. Next, we graphed national averages of u5 children who are undernourished (stunted, wasted) and percentage of households with personal toilets for 3 time points: 2005–2006, 2013–2014, and 2015–2016.

[1] DLHS, AHS, and NFHS report household toilet availability based on response to the following question: "What kind of toilet facility do members of your household usually use?" The list of responses (in all 3 surveys) includes a) flush to piped sewer system; b) flush to septic tank; c) flush to pit latrine; d) flush to somewhere else; e) flush, don't know where; f) pit ventilated improved biogas latrine; g) pit latrine with slab; h) pit latrine without slab/open pit; i) twin pit/composting toilet; j) dry toilet; k) no facility/uses open space or field; and l) other. We identified household-level responses (a–i) as indicative of a presence of a toilet in that household. The AHS, DLHS, and NFHS surveys also ask if the reported toilet facility is shared by persons from other households (survey question: "Do you share this toilet facility with other households?"). We only included, in our enumeration, toilets that were not shared with persons from other households/community to develop the exposure (percentage of households with personal toilet). Survey weights for all covariates were retrieved from the AHS, DLHS, and NFHS, respectively.

Empirical estimation

Our test, often referred to as a "difference-in-difference" analysis in the evaluation literature (59), turns on whether the u5 child health outcomes improve above expected levels following districts' increase in toilet construction from the pre- to post-SBM period. We use ordinary least squares regression to estimate the following equation:

$$\begin{aligned} \mathrm{Y}_{\mathrm{i,t,r}} = \beta_0 &+ \beta_1 \mathrm{Toilet}_{\mathrm{i,t,r}} + \beta_2 \mathrm{SBM}_{\mathrm{t}} \\ &+ \beta_3 \mathrm{Toilet}_{\mathrm{i,t,r}} * \mathrm{SBM}_{\mathrm{t}} + \beta_4 \mathbf{Z}_{\mathrm{i,t,r}} \\ &+ \beta_5 \mathbf{State} * \mathbf{year} + \beta_6 \mathrm{Rural} + \beta_7 \mathbf{District}_{\mathrm{i}} + \varepsilon_{\mathrm{i,t,r}} \quad (1) \end{aligned}$$

where $\mathrm{Y}_{i,t,r}$ is the percentage of u5 children who are stunted or wasted (separate variables) in district *i* at time *t* (pre-SBM, post-SBM) in region *r* (rural, urban). $\mathrm{Toilet}_{i,t,r}$ is the percentage of households with toilets in district *i* at time *t* and region *r*. SBM_t is a binary variable coded 0 for pre-SBM and 1 for post-SBM. β_3 is the main coefficient of interest that represents the interaction between SBM and percentage change (pre- to post-SBM) of households with toilets. Put another way, the parameter estimates the "net association" between SBM-related toilet construction and change in child health outcome. $\mathbf{Z}_{i,t,r}$ is a vector of control variables comprising district-level aggregates of maternal education (matriculate or 10th grade and above), institutional delivery (hospital birth), child immunization, maternal health care during pregnancy (at least 4 antenatal care visits), households with access to electricity, clean drinking water (boiled, chlorinated, or treated with alum; filtered using electric filters or composite materials), clean cooking fuel (liquid petroleum gas, biogas), and district wealth (deciles) in district *i* at time *t* in region *r*. District wealth deciles were created using methods described by Filmer and Pritchett (60) (excluding electricity, source of water, toilet availability, and cooking fuel as we controlled for these factors separately). These variables control for district-level socioeconomic attributes, access to health systems, and child health correlates other than toilets (61–63). We estimate **Equation 1** for the full sample (overall) and stratified by rural/urban regions.

We do not control for diarrhea as it falls on the hypothesized pathway linking poor sanitation (open defecation) to child undernutrition (63). The collection of information on diarrhea, moreover, relies on reporting based on its occurrence in the 2 wk preceding each survey, which makes it an acute rather than chronic outcome and also introduces bias from seasonality (diarrhea is more common during summer/monsoon seasons relative to winter). **State * year** is the vector of state-specific linear time trends that control for state-specific factors that may vary linearly over time for the duration of our study. Examples of such factors include state-level policies that affect sanitation as well as child undernutrition and state-specific trends in income, health system access, and cultural, dietary norms. Rural is a binary identifier of aggregation level by rural/urban location of households within districts, based on Indian census criteria of population density and predominant type of economic activity (agrarian compared with others). $\mathbf{District}_i$ is a vector of district-level fixed effects that accounts for time-invariant attributes of districts that may influence child undernutrition. $\varepsilon_{i,t,r}$ is the cluster-robust standard error term.

Owing to the distinct nature of SBM-G (rural) and SBM-U (urban), we also estimate Equation 1 for rural and urban units separately. We exclude state-specific linear time trends for the rural/urban stratified regression analyses owing to reduction in sample size (and statistical power) by half, but we retained district fixed effects. We also estimate Equation 1 using only the baseline (i.e., pre-SBM) percentage of households with personal toilets to examine whether baseline toilet availability affected the strength of the relation between new toilet construction and u5 health outcomes. Last, we perform the multiple sensitivity checks to ensure robustness of all findings and to identify potential circumstances in which any discovered SBM campaign "effect" might have been most salient.

TABLE 1 Mean (SD) of district-level aggregate variables by rural/urban region across pre- and post-SBM periods in India[1]

Variable	Pre-SBM (2012–2013)		Post-SBM (2015–2016)	
	Rural	Urban	Rural	Urban
Sample size	563	564	627	637
Percentage of households with personal toilet	38.1 (27.9)	65.1 (16.7)	46.1 (27.1)	70.6 (14.9)
Percentage of u5 children who are stunted	48.8 (14.0)	43.7 (17.5)	37.3 (10.6)	30.7 (11.4)
Percentage of u5 children who are wasted	23.2 (10.3)	21.8 (12.5)	20.9 (8.7)	19.4 (9.8)
Percentage of u5 children who are severely stunted	26.4 (12.2)	23.5 (14.9)	15.8 (7.0)	12.7 (7.1)
Percentage of u5 children who are severely wasted	10.9 (7.5)	11.2 (8.7)	8.0 (5.2)	8.7 (6.6)
Percentage of households with clean drinking water	17.3 (25.0)	30.7 (26.1)	22.4 (26.8)	39.0 (25.7)
Percentage of institutional deliveries	68.5 (22.3)	82.2 (16.0)	77.3 (18.4)	87.3 (14.2)
Percentage of households with clean cooking fuel	17.2 (19.0)	60.7 (20.8)	24.9 (19.4)	72.7 (17.8)
Percentage of households with electricity	65.4 (33.8)	83.8 (19.2)	86.0 (16.2)	96.4 (5.6)
Percentage of women with at least 10 y of schooling	21.0 (14.7)	42.8 (14.2)	28.9 (14.2)	49.4 (12.8)
Percentage of women who reported 4 ANC visits during pregnancy	41.6 (27.1)	60.9 (24.2)	45.3 (32.6)	67.1 (28.8)
Percentage of children who received full immunization	62.7 (9.9)	65.6 (8.7)	63.4 (9.9)	66 (8.7)
District wealth decile	4.8 (2.9)	5.8 (2.9)	5.2 (2.6)	6.2 (2.8)

[1]Values are mean (SD). ANC, Antenetal Care; SBM, Swachh Bharat Mission; u5, under 5-y-old.

Results

Post-SBM, the percentage of households with personal toilets increased by 12% in rural and by 5% in urban areas, relative to pre-SBM (**Table 1**). Over the same period, the percentage of u5 children who are stunted declined by almost 10% in rural and 7% in urban areas. However, the percentage of u5 children who are wasted stayed nearly constant from pre- to post-SBM. **Supplemental Figure 1** shows the scatterplot overlaid with unadjusted linear fit of our exposure compared with outcomes at the district level, by rural and urban regions in India. The slope of the linear fit between percentage of households with personal toilets and u5 stunting is negative and marginally steeper post-SBM relative to pre-SBM for rural districts (Supplemental Figure 1). The percentage of u5 children who are wasted stays nearly constant over pre- and post-SBM in urban districts, although its linear fit with respect to toilet availability post-SBM shows a steeper slope relative to pre-SBM among rural districts (**Supplemental Figure 2**).

Supplemental Figures 3 and **4** map the change in percentage of u5 children who are stunted and percentage of households with personal toilets. Post-SBM, most districts in India show increased toilet availability (Supplemental Figure 3). We also observe a marked decline in u5 stunting in these states post-SBM (Supplemental Figure 4).

The relation between regional toilet availability and u5 stunting in India was constant in the time periods preceding SBM, thus supporting the "constant slope" assumption (**Supplemental Figure 5, Supplemental Table 1**). **Table 2** shows the main results from linear fixed-effects (district-level) regression analyses for stunting and wasting in u5 children, overall and by rural/urban regions. The coefficient of the interaction term (SBM ∗ percentage of households with personal toilets) gives the "net association" of SBM with u5 stunting and wasting. Results from the analysis of the overall sample (inclusive of rural and urban districts) support the hypothesis in that, relative to pre-SBM, stunting declined by 0.06 percentage points per unit (or 1%) increase in household-level toilet availability post-SBM ($P = 0.009$) (Table 2, model 1). However, there was no change in the percentage of u5 children who are wasted with the change in toilet availability (Table 2, models 2, 4, 6). The decline in u5 stunting concentrates among rural areas (coefficient = –0.05, $P = 0.023$) (Table 2, model 3). These results underscore the role of SBM-G relative to SBM-U in reducing child undernutrition over our study period (Table 2, models 3, 5). **Supplemental Figure 6** provides a "visual" depiction of our interaction test, in which we graph the predicted values of u5 stunting (average marginal effects, based on Equation 1) over incremental values of percentage of households with toilets, for pre- and post-SBM time periods (64). The slope of predicted u5 stunting is steeper over the post-SBM period compared with pre-SBM. This *difference in slopes* of linear prediction over pre-SBM, relative to post-SBM, illustrates the association between u5 stunting and SBM ∗ percentage of households with personal toilets interaction term (Supplemental Figure 6).

We also examined whether a district's baseline level of toilets pre-SBM affects the strength of the findings. **Table 3** indicates that higher toilet availability pre-SBM corresponds with a greater reduction in u5 stunting (but not wasting) post-SBM (coefficient = –0.05, $P = 0.031$). This finding suggests that districts with a relatively higher baseline toilet availability showed a greater decline in u5 stunting compared with districts that formerly had a lower percentage of household toilets. In addition, relative to districts at the lowest *quartile* of toilet availability at the pre-SBM baseline, u5 stunting declines to a greater degree among districts at higher baseline toilet quartiles (**Supplemental Figures 7, 8; Supplemental Table 2**). Results from Table 3 and Supplemental Table 2 suggest that u5 stunting may exhibit a nonlinear response to an increase in district-level toilet availability. Whereas all the interaction coefficients in Supplemental Table 2 are negative, only the estimate for SBM ∗ third quartile reaches conventional levels of statistical significance for u5 stunting (Supplemental Table 2, model 1). In our data, districts at the third quartile of baseline toilet availability show a mean of 64% (percentage of households with personal toilets) pre-SBM. Within these districts, the mean percentage of households with personal toilets increases to 72% post-SBM. These patterns indicate that increasing toilet availability to >70% may likely elicit reductions in u5 stunting. This nonlinear association has also been observed in other studies and suggests that improvements in child undernutrition may correspond with achievement of sanitation coverage "thresholds," underscoring the negative externality of open defecation (28, 65, 66).

Exploratory age group-specific analyses suggest that the overall decline in u5 stunting reported in Table 2 concentrates

TABLE 2 Ordinary least squares fixed-effects regression results for full sample and by rural/urban districts[1]

Overall sample (inclusive of rural and urban districts)

	Model 1: Outcome = percentage of u5 children who are stunted			Model 2: Outcome = percentage of u5 children who are wasted		
Covariates	Coefficient	95% CI	*P* value	Coefficient	95% CI	*P* value
Post-SBM (reference = pre-SBM)	4.57	−3.18, 12.33	0.247	1.74	−6.61, 10.09	0.682
Baseline (pre-SBM) percentage of households with personal toilet	− 0.01	−0.06, 0.05	0.848	− 0.02	−0.06, 0.02	0.380
SBM ∗ baseline percentage of households with personal toilet (reference = pre-SBM)	− 0.06	−0.10, −0.01	0.009	− 0.01	−0.04, 0.03	0.684
Percentage of households with clean water	− 0.08	−0.17, 0.01	0.094	− 0.05	−0.12, 0.01	0.091
Percentage of households with clean cooking fuel	0.05	−0.02, 0.11	0.193	0.03	−0.04, 0.10	0.458
Percentage of households with electricity	− 0.05	−0.11, 0.01	0.103	− 0.01	−0.05, 0.04	0.707
Percentage of women with at least 10 y of schooling	− 0.17	−0.29, −0.05	0.007	0.02	−0.09, 0.14	0.663
Percentage of institutional deliveries	− 0.06	−0.15, 0.04	0.257	0.00	−0.06, 0.06	0.940
Percentage of women who reported 4 ANC visits during pregnancy	− 0.05	−0.12, 0.02	0.182	− 0.03	−0.08, 0.03	0.377
Percentage of children who received full immunization	0.00	−0.13, 0.13	0.985	− 0.01	−0.12, 0.09	0.791
District wealth decile	− 1.66	−3.27, −0.05	0.044	− 1.57	−2.75, −0.38	0.009
Urban (reference = rural)	− 0.15	−2.56, 2.26	0.903	− 0.87	−3.70, 1.96	0.548
Mean of dependent variable		39.65			33.0	
Sample size		2317			2310	

Rural

	Model 3: Outcome = percentage of u5 children who are stunted			Model 4: Outcome = percentage of u5 children who are wasted		
Covariates	Coefficient	95% CI	*P* value	Coefficient	95% CI	*P* value
Post-SBM (reference = pre-SBM)	− 4.67	−8.00, −1.34	0.006	− 6.44	−10.16, −2.72	0.00
Baseline (pre-SBM) percentage of households with personal toilet	0.09	−0.03, 0.21	0.162	0.05	−0.06, 0.16	0.36
SBM ∗ baseline percentage of households with personal toilet (reference = pre-SBM)	− 0.05	−0.10, −0.01	0.023	− 0.03	−0.08, 0.02	0.27
Percentage of households with clean water	− 0.09	−0.23, 0.04	0.183	− 0.01	−0.17, 0.15	0.89
Percentage of households with clean cooking fuel	− 0.12	−0.25, 0.01	0.073	0.20	0.00, 0.40	0.05
Percentage of households with electricity	− 0.07	−0.13, 0.00	0.048	0.05	−0.01, 0.12	0.08
Percentage of women with at least 10 y of schooling	− 0.17	−0.36, 0.02	0.073	0.09	−0.17, 0.34	0.50
Percentage of institutional deliveries	− 0.08	−0.21, 0.06	0.267	0.14	0.00, 0.29	0.05
Percentage of women who reported 4 ANC visits during pregnancy	0.01	−0.02, 0.04	0.337	− 0.05	−0.08, −0.03	0.00
Percentage of children who received full immunization	− 0.17	−0.31, −0.03	0.015	0.00	−0.15, 0.16	0.95
District wealth decile	− 1.39	−3.02, 0.23	0.093	0.15	−1.68, 1.97	0.87
Mean of dependent variable		42.62			21.94	
Sample size		1169			1163	

(*Continued*)

TABLE 2 (*Continued*)

Urban

Covariates	Model 5: Outcome = percentage of u5 children who are stunted			Model 6: Outcome = percentage of u5 children who are wasted		
	Coefficient	95% CI	*P* value	Coefficient	95% CI	*P* value
Post-SBM (reference = pre-SBM)	−6.60	−15.43, 2.23	0.143	−5.58	−13.07, 1.91	0.14
Baseline (pre-SBM) percentage of households with personal toilet	0.10	−0.08, 0.27	0.284	0.01	−0.12, 0.14	0.86
SBM ∗ baseline percentage of households with personal toilet (reference = pre-SBM)	−0.03	−0.15, 0.09	0.577	0.02	−0.08, 0.12	0.73
Percentage of households with clean water	−0.18	−0.39, 0.03	0.088	0.01	−0.12, 0.14	0.85
Percentage of households with clean cooking fuel	0.13	−0.09, 0.35	0.235	0.04	−0.15, 0.24	0.65
Percentage of households with electricity	−0.18	−0.33, −0.03	0.022	0.07	−0.06, 0.19	0.32
Percentage of women with at least 10 y of schooling	−0.24	−0.45, −0.03	0.024	0.04	−0.12, 0.21	0.59
Percentage of institutional deliveries	−0.01	−0.23, 0.20	0.917	0.07	−0.08, 0.21	0.38
Percentage of women who reported 4 ANC visits during pregnancy	0.00	−0.06, 0.06	0.948	−0.06	−0.11, −0.01	0.01
Percentage of children who received full immunization	−0.05	−0.27, 0.17	0.665	−0.02	−0.17, 0.13	0.79
District wealth decile	−2.18	−4.73, 0.36	0.093	−2.62	−4.84, −0.40	0.02
Mean of dependent variable		36.63			20.49	
Sample size		1148			1128	

[1]Outcome for model 1: percentage of u5 children who are stunted in the overall sample (inclusive of rural and urban districts); Outcome for model 2: percentage of u5 children who are wasted in the overall sample (inclusive of rural and urban districts); Outcome for model 3: percentage of u5 children who are stunted in rural districts; Outcome for model 4: percentage of u5 children who are wasted in rural districts; Outcome for model 5: percentage of u5 children who are stunted in urban districts; and Outcome for model 6: percentage of u5 children who are wasted in urban districts. All outcomes predicted as a function of SBM status (post-SBM) and percentage of households with personal toilets per district in India. District fixed effects and state-specific linear time trend covariates not shown. ANC, antenatal care; SBM, Swachh Bharat Mission; u5, under 5 y old.

among the ≥2-y (i.e., 2-y to 4-y, 11-mo-old) age group (**Supplemental Table 3**). We observe no statistically detectable relations between age group-specific wasting and percentage of households with toilets. In addition, when examining extremely adverse health outcomes, the increase in household toilets post-SBM corresponds with a reduction in severe u5 stunting (very small magnitude of coefficient observed in relation to severe u5 wasting) (**Supplemental Table 4**).

Last, we reestimated our main equation but used odds of u5 health as the outcome at the individual level instead of at the aggregate district level. In addition to covariates specified in Equation 1, these individual-level analyses also controlled for month of birth and month of survey (**Supplemental Table 5**). Inference remains similar to the main results in that we observe SBM-related reduction in the odds of u5 stunting (Supplemental Table 5, model 1). However, contrary to our other analyses (but in alignment with Supplemental Figure 2), individual-level estimations also show a decline in the odds of wasting among u5 children (Supplemental Table 5, model 2).

Whereas the magnitude of our estimates appears modest, we deem these findings as plausible in light of prior work that reports qualitatively similar results from smaller-scale experimental analyses (24, 28). To give the reader a sense of the magnitude of the findings, we estimated the predicted change in u5 stunting cases following the SBM campaign. About 50 million u5 Indian children were stunted pre-SBM (1). This figure fell by 10% post-SBM (Table 1) with 5 million fewer u5 stunted children in 2015–2016. Of this decline, 0.06% less u5 stunting occurs with each 1-unit (1%) increase in intrahousehold toilet availability post-SBM (based on our results). Application of our discovered coefficient to this stunting decline and the observed increase in toilets (i.e., 0.0006 ∗ 5 million ∗ 8) yields 24,000 fewer u5 stunted children (ranging from 4000 to 40,000 based on 95% CI of interaction term coefficient reported in Table 2) statistically attributable to an increase in toilet availability following SBM. Given the age-specific patterns observed in Supplemental Table 3, we contend that this reduction concentrates among u5 children older than 2 y of age.

Discussion

Relative to other developing countries, India remains an outlier with respect to high undernutrition in general and wasting in particular among u5 children (2, 3). The widespread practice of open defecation among the Indian population appears to explain this anomaly (particularly for stunting) (4), although there is some debate (67). We test whether the early phase (i.e., first 2 y) of a large-scale national sanitation campaign in India—the SBM—corresponds with an increase in household-level toilet availability and concurrent decline in undernutrition (stunting and wasting) among u5 children. Results show that a 1% increase in district-level household toilet availability post-SBM (relative to pre-SBM) correlates with a 0.06% decline in u5 stunting, but we observe no changes in u5 wasting. Reduction in u5 stunting post-SBM appears to concentrate in rural areas.

Intriguingly, whereas the first 1000 d of life (i.e., ages 0–2 y) remain one of the most vulnerable time periods for child growth and development, we find no relation between improved ambient sanitation and stunting in this age group. Our analyses, rather, show reduced stunting among children aged 2–5 y, following increased toilet availability post-SBM. We speculate, post hoc, that this circumstance may arise for 2 reasons. First, other researchers have described "exposure bias"—the

TABLE 3 Ordinary least squares fixed-effects regression results using baseline (i.e. pre-SBM) toilet availability as interacted exposure[1]

Covariates	Model 1: Outcome = percentage of u5 children who are stunted			Model 2: Outcome = percentage of u5 children who are wasted		
	Coefficient	95% CI	*P* value	Coefficient	95% CI	*P* value
Post-SBM (reference = pre-SBM)	4.47	−2.70, 11.65	0.222	1.34	−5.27, 7.94	0.692
Baseline (pre-SBM) percentage of households with personal toilet	− 0.01	−0.07, 0.04	0.665	− 0.03	−0.08, 0.01	0.141
SBM ∗ baseline percentage of households with personal toilet (reference = pre-SBM)	− 0.05	−0.09, 0.00	0.031	0.00	−0.04, 0.04	0.978
Percentage of households with clean water	− 0.09	−0.18, 0.00	0.047	− 0.07	−0.14, 0.00	0.064
Percentage of households with clean cooking fuel	0.06	−0.01, 0.13	0.104	0.03	−0.04, 0.10	0.443
Percentage of households with electricity	− 0.06	−0.11, 0.00	0.059	− 0.01	−0.05, 0.04	0.787
Percentage of women with at least 10 y of schooling	− 0.20	−0.31, −0.08	0.001	0.05	−0.06, 0.16	0.366
Percentage of institutional deliveries	− 0.05	−0.15, 0.04	0.286	− 0.02	−0.08, 0.05	0.604
Percentage of women who reported 4 ANC visits during pregnancy	− 0.06	−0.12, 0.01	0.094	− 0.03	−0.08, 0.02	0.283
Percentage of children who received full immunization	0.04	−0.09, 0.16	0.554	− 0.01	−0.11, 0.08	0.766
District wealth decile	− 1.62	−3.21, −0.02	0.047	− 1.76	−3.04, −0.47	0.007
Urban (reference = rural)	0.21	−2.33, 2.76	0.869	− 0.50	−3.48, 2.48	0.741
Mean of dependent variable		39.65			33.0	
Sample size		2317			2310	

[1]Outcome for model 1: percentage of u5 children who are stunted; Outcome for model 2: percentage of u5 children who are wasted. All outcomes predicted as a function of SBM status (post-SBM) and baseline (pre-SBM) percentage of households with personal toilets per district in India interaction term. District fixed effects and state-specific linear time trend covariates not shown. ANC, antenatal care; SBM, Swachh Bharat Mission; u5, under 5 y old.

attenuation of benefits from postnatal protective factors—as a potential reason for lower statistical detection of associations between child growth and environmental exposures among under 2-y-old children (68). Factors associated with postnatal nutritional insults or benefits may not have manifested fully among children aged 0–2 y, making it difficult to gauge stable relations in statistical tests (68). It is also plausible that accrued effects of environmental exposures (e.g., improved sanitation) over the first 1000 d of life may correspond with reduced stunting among 2- to 5-y-old children, indicating a lagged response that becomes "visible" during later childhood (69). Second, reduced reliance on breastfeeding, increased mobility, and greater exposure to contaminated food, water, soil, and surfaces among 2- to 5-y-old children, relative to those under 2 y old, may also account for our age-specific results (23, 65, 66). We further note that the absence of any relation between stunting and increased toilet availability following SBM among children aged <2 y in our analyses coheres with findings from randomized sanitation trials that report no changes in undernutrition during early childhood (first 1000 d of life) following sanitation improvements in other developing countries (13–19).

To our knowledge, this is the first study to examine one of the largest and current public health campaigns with respect to u5 child health outcomes in a nationally representative, longitudinal manner. Strengths of our study include the timing and variable intensity of toilet construction of SBM across districts. In addition, we use nationally representative data sets encompassing the majority of districts in India. A key aspect of our study involves the use of well-timed survey data sets shortly before and up to 2 y after SBM, which offers a quasi-experimental circumstance and reduces concerns of maturation bias (70). We, moreover, adjust for other important determinants of stunting and wasting among u5 children. Our use of district-level fixed effects and state-level linear time trends further minimizes confounding from inherent regional differences and shared antecedents of child undernutrition across Indian districts.

Limitations include that, as with any nonrandomized study in which the intervention occurred in all regions, we cannot exclude the possibility of unmeasured confounding. We attempted to minimize this possibility in several ways. First, our "difference-in-difference" study design exploits variation in intensity of toilet construction in the 2 y immediately following SBM. Second, inclusion of several district-level covariates known to predict infrastructure quality, economic status, and child growth do not affect inference. Third, we relied on responses from individual surveys, rather than from governmental reports, to capture our key exposure of intensity of changes in toilet construction. Use of the validated survey data minimizes any circumstance in which a third party skewed sanitation and child health statistics to "favor" a result showing SBM effectiveness. Fourth, our extensive sensitivity analyses indicate consistency of results.

However, owing to the observational nature of our study, the potential for confounding from unobserved factors remains. E-value estimates indicate that for our findings to arise from a common confounder, this unobserved confounder would have to account for a simultaneous increase in the exposure and decline in our outcome by at least 1.30 percentage points (71). We control for several key factors that may exhibit such large associations with the outcome and exposure in our analyses (district wealth decile, maternal education, maternal stature through district fixed effects) (72, 73). We, however, do not control for infant and young child feeding (IYCF) practices in our ecologic analyses (owing to limited comparability of IYCF measurement methods across our pre- and post-SBM data sets). We encourage future research to use our estimated E-value of 1.30 in subjecting our analyses to test for rival explanations and confounders.

Some scholars note that the widespread use of height-for-age Z score (HAZ) may obscure patterns observed through alternate anthropometric measures such as height-for-age difference (HAD) (74). We encourage future research to examine the role of SBM in reducing HAD using individual-level longitudinal data.

Recent reports suggest that India may have reversed its previous improvements in child undernutrition owing to economic instability and gross domestic product decline between 2016 and 2019 (75–77). Given that wealth plays a key role in child undernutrition, macroeconomic decline owing to policies such as national demonetization may have adversely affected household income and child health outcomes, particularly among low-income households in India (78, 79).

Research finds that toilet ownership does not necessarily correspond with toilet use, particularly in North Indian regions where members of households with toilets may still prefer to practice open defecation owing to religious beliefs about purity, cleanliness, quality of in-house toilets, and long-term habits (31, 32, 80). The practice of caste-based discrimination, or "untouchability," represents one of the key drivers of persistent open defecation in India (81). Even when private household toilets are available, individuals may not use them owing to cultural perception of cleaning toilets or emptying sewage tanks/pits as impure or unholy activities (31, 32, 81). Disposal of human waste has traditionally been relegated to "lower" castes. Deeply ingrained discriminatory ideology informs widespread personal preferences such that defecating in the open appears preferable to cleaning or managing human excreta, particularly among rural North Indian populations (31, 32, 81). We encourage future research to examine the variation in casteism following SBM's intensive public messaging efforts, in relation to toilet use and child health outcomes. Our study's data sets also are limited in that they do not contain specific information about preference for toilet use.

The observation that greater toilet availability at pre-SBM baseline corresponds with greater reductions in u5 stunting deserves comment. Our results may help explain other studies that have null effects as modest reductions in open defecation are unlikely to have a detectable effect on child stunting. Consistent with Gertler et al. (28), these results suggest that comprehensive interventions like SBM that combine both intensive health promotional nudges and financial subsidies for sanitation construction may be needed to reduce open defecation enough to generate meaningful improvements in child health. We remind the reader that this explanation is post hoc and requires further rigorous refinement and testing.

We do not observe any changes in u5 stunting in urban areas. It is plausible that urban areas, owing to higher population density and potentially greater risk of transmission of fecal pathogens, may require greater investments under SBM-U to improve child undernutrition (12, 63). Concerningly, we also do not observe any decline in wasting among u5 children following increased toilet availability post-SBM. Wasting reflects acute undernutrition and may result from transient food shortage and disease (82, 83). Loss of (or inadequate) muscle mass during periods of nutritional deprivation likely predisposes children to wasting (82, 83). Based on our findings and current literature, we contend that sanitation improvements alone may not be sufficient toward addressing India's high burden of u5 wasting. Concerted efforts toward protein, energy, and micronutrient dietary supplementation may help improve this indicator of undernutrition in Indian children (82, 83).

Conclusion

Our analysis of the introduction of SBM, one of the largest-ever sanitation interventions in terms of scale and funding, indicates that a multifaceted sanitation campaign may have reduced growth retardation in u5 children by a modest magnitude over the early phase of its implementation. We encourage replication of our findings and examination of later time points in the SBM rollout.

Author Contributions

The authors' contributions were as follows—PS and TB: designed the study (project conception, development of overall research plan, and study oversight) and had primary responsibility for final content; PS and MS: conducted data analysis (hands-on conduct of analysis and data collection); TB: provided essential materials; PS, MS, and TB: contributed equally to writing the manuscript and preparing it for submission; and all authors: read and approved the final manuscript.

Data Availability

The data sets underlying this article were derived from sources in the public domain: Annual Health Survey (AHS) India, Office of the Registrar General and Census Commissioner (India), 2014 (http://www.censusindia.gov.in/2011census/hh-series/cab.html); District Level Household and Facility Survey (DLHS-4), 2012–2013. IIPS, International Institute of Population Sciences, Mumbai, India, 2014 (http://www.nrhmmis.nic.in/SitePages/DLHS-4.aspx); and International Institute for Population Sciences (IIPS) and ICF, National Family Health Survey (NFHS-4), 2015–2016, Mumbai, India, 2017 (https://dhsprogram.com/pubs/pdf/FR339/FR339.pdf).

References

1. Fanzo J, Hawkes C, Udomkesmalee E, Akshin A, Allemandi L, Assery O. Global nutrition report: shining a light to spur action on nutrition [Internet]. 2018 [cited June 3, 2021]. Available from: https://globalnutritionreport.org/reports/global-nutrition-report-2018/
2. Spears D. Exposure to open defecation can account for the Indian enigma of child height. J Dev Econ. Elsevier; 2018;102277.
3. UNICEF, WHO, The World Bank. Level and trends in child malnutrition UNICEF-WHO-World Bank group joint child malnutrition estimates: key findings of the 2015 editions [Internet]. 2015 [cited June 3, 2021]. Available from: https://www.who.int/nutgrowthdb/jme-2019-key-findings.pdf.
4. Spears D. How much international variation in child height can sanitation explain? Washington DC: The World Bank; 2013.
5. Spears D, Ghosh A, Cumming O. Open defecation and childhood stunting in India: an ecological analysis of new data from 112 districts. PLoS One 2013;8:e73784.
6. Humphrey JH. Child undernutrition, tropical enteropathy, toilets, and handwashing. Lancet 2009;374:1032–5.
7. Korpe PS, Petri WA. Environmental enteropathy: critical implications of a poorly understood condition. Trends Mol Med 2012;18:328–36.
8. Black RE, Victora CG, Walker SP, Bhutta ZA, Christian P, De Onis M, Ezzati M, Grantham-McGregor S, Katz J, Martorell R. Maternal and child undernutrition and overweight in low-income and middle-income countries. Lancet 2013;382:427–51.
9. Bhutta ZA, Das JK, Rizvi A, Gaffey MF, Walker N, Horton S, Webb P, Lartey A, Black RE; Group TLNIR. Evidence-based interventions for improvement of maternal and child nutrition: what can be done and at what cost? Lancet 2013;382:452–77.
10. Martorell R. The nature of child malnutrition and its long-term implications. Food Nutr Bull 1999;20:288–92.
11. Alderman H, Hoddinott J, Kinsey B. Long term consequences of early childhood malnutrition. Oxf Econ Pap 2006;58:450–74.
12. Hathi P, Haque S, Pant L, Coffey D, Spears D. Place and child health: the interaction of population density and sanitation in developing countries. Washington DC: The World Bank; 2014.
13. Stewart CP, Kariger P, Fernald L, Pickering AJ, Arnold CD, Arnold BF, Hubbard AE, Dentz HN, Lin A, Meerkerk TJ. Effects of water

quality, sanitation, handwashing, and nutritional interventions on child development in rural Kenya (WASH Benefits Kenya): a cluster-randomised controlled trial. Lancet Child Adolesc Health 2018;2: 269–80.

14. Luby SP, Rahman M, Arnold BF, Unicomb L, Ashraf S, Winch PJ, Stewart CP, Begum F, Hussain F, Benjamin-Chung J. Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Bangladesh: a cluster randomised controlled trial. Lancet Glob Health 2018;6: e302–15.
15. Null C, Stewart CP, Pickering AJ, Dentz HN, Arnold BF, Arnold CD, Benjamin-Chung J, Clasen T, Dewey KG, Fernald LCH. Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Kenya: a cluster-randomised controlled trial. Lancet Glob Health 2018;6:e316–29.
16. Humphrey JH, Mbuya MNN, Ntozini R, Moulton LH, Stoltzfus RJ, Tavengwa N V, Mutasa K, Majo F, Mutasa B, Mangwadu G. Independent and combined effects of improved water, sanitation, and hygiene, and improved complementary feeding, on child stunting and anaemia in rural Zimbabwe: a cluster-randomised trial. Lancet Glob Health 2019;7:e132–47.
17. Cameron L, Olivia S, Shah M. Scaling up sanitation: evidence from an RCT in Indonesia. J Dev Econ 2019;138:1–16.
18. Pickering AJ, Null C, Winch PJ, Mangwadu G, Arnold BF, Prendergast AJ, Njenga SM, Rahman M, Ntozini R, Benjamin-Chung J. The WASH Benefits and SHINE trials: interpretation of WASH intervention effects on linear growth and diarrhoea. Lancet Glob Health 2019;7: e1139–46.
19. Cumming O, Curtis V. Implications of WASH Benefits trials for water and sanitation. Lancet Glob Health 2018;6:e613–4.
20. Coffey D, Spears D. Implications of WASH benefits trials for water and sanitation. Lancet Glob Health 2018;6:e615.
21. Arnold BF, Null C, Luby SP, Colford JM. Implications of WASH Benefits trials for water and sanitation—authors' reply. Lancet Glob Health 2018;6:e616–7.
22. Cumming O, Arnold BF, Ban R, Clasen T, Mills JE, Freeman MC, Gordon B, Guiteras R, Howard G, Hunter PR. The implications of three major new trials for the effect of water, sanitation and hygiene on childhood diarrhea and stunting: a consensus statement. BMC Med 2019;17:1–9.
23. Rah JH, Cronin AA, Badgaiyan B, Aguayo VM, Coates S, Ahmed S. Household sanitation and personal hygiene practices are associated with child stunting in rural India: a cross-sectional analysis of surveys. BMJ Open 2015;5:e005180.
24. Hammer J, Spears D. Village sanitation and child health: effects and external validity in a randomized field experiment in rural India. J Health Econ 2016;48:135–48.
25. Dearden KA, Schott W, Crookston BT, Humphries DL, Penny ME, Behrman JR. Children with access to improved sanitation but not improved water are at lower risk of stunting compared to children without access: a cohort study in Ethiopia, India, Peru, and Vietnam. BMC Public Health 2017;17:110.
26. Clasen T, Boisson S, Routray P, Torondel B, Bell M, Cumming O, Ensink J, Freeman M, Jenkins M, Odagiri M. Effectiveness of a rural sanitation programme on diarrhoea, soil-transmitted helminth infection, and child malnutrition in Odisha, India: a cluster-randomised trial. Lancet Glob Health 2014;2:e645–53.
27. Patil SR, Arnold BF, Salvatore AL, Briceno B, Ganguly S, Colford Jr JM, Gertler PJ. The effect of India's total sanitation campaign on defecation behaviors and child health in rural Madhya Pradesh: a cluster randomized controlled trial. PLoS Med 2014;11: e1001709.
28. Gertler P, Shah M, Alzua ML, Cameron L, Martinez S, Patil S. How does health promotion work? Evidence from the dirty business of eliminating open defecation. National Bureau of Economic Research; 2015. WORKING PAPER 20997.
29. Headey D, Palloni G. Water, sanitation, and child health: evidence from subnational panel data in 59 countries. Demography 2019;56: 729–52.
30. Coffey D, Spears D. Open defecation in rural India, 2015–2016: levels and trends in the NFHS-4. Econ Polit Wkly 2018;53:10–3.
31. Spears D, Thorat A. The puzzle of open defecation in rural India: evidence from a novel measure of caste attitudes in a nationally representative survey. Econ Dev Cult Change 2019;67:725–55.
32. Coffey D, Gupta A, Spears D, Khurana N, Srivastav N, Hathi P, Vyas S. Evidence from a new survey in rural North India: revealed preference for open defecation. Econ Polit Wkly 2014;49:43–55.
33. Department of Drinking Water & Sanitation, Ministry of Jal Shakti, Government of India. Swachh Bharat Mission [Internet] [cited June 3, 2021]. Available from: https://swachhbharatmission.gov.in/sbmcms/index.htm
34. Ministry of Housing and Urban Affairs, Government of India. Swachh Bharat Mission Urban (SBM-U) [Internet]. 2019 [cited June 3, 2021]. Available from: http://swachhbharaturban.gov.in/
35. Dalberg WASH Institute. An assessment of the reach and value of IEC activities under Swachh Bharat Mission (Grameen) [Internet]. 2019 [cited June 3, 2021]. Available from: https://jalshakti-ddws.gov.in/sites/default/files/201906_SBM_IEC_Whitepaper.pdf
36. Mohapatra G. Projected behavioural change in Swachh Bharat Mission: a public policy perspective. Indian J Public Adm 2019;65:451–74.
37. Exum NG, Gorin EM, Sadhu G, Khanna A, Schwab KJ. Evaluating the declarations of open defecation free status under the Swachh Bharat ('Clean India') Mission: repeated cross-sectional surveys in Rajasthan, India. BMJ Glob Health 2020;5:e002277.
38. Andres LA, Deb S, Joseph G, Larenas MI, Grabinsky Zabludovsky J. A multiple-arm, cluster-randomized impact evaluation of the Clean India (Swachh Bharat) Mission program in rural Punjab, India. Policy Research Working Paper 9249. Washington DC: World Bank Group-Water Global Practice; 2020.
39. Curtis V. Explaining the outcomes of the "Clean India" campaign: institutional behaviour and sanitation transformation in India. BMJ Glob Health 2019;4:e001892.
40. UNICEF. UNICEF report on the environmental impact of the Swachh Bharat Mission on water, soil and food [Internet]. 2019 [cited June 3, 2021]. Available from: https://www.unicef.org/india/reports/report-environmental-impact-swachh-bharat-mission-sbm-water-soil-and-food.
41. Gupta A, Khalid N, Devashish D, Hathi P, Avani K, Srivastav N, Vyas S, Spears D, Coffey D. Changes in open defecation in rural North India: 2014–2018 [Internet]. 2019 [cited June 3, 2021]. Available from: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3323179.
42. Dandabathula G, Bhardwaj P, Burra M, Rao P, Rao SS. Impact assessment of India's Swachh Bharat Mission—Clean India Campaign on acute diarrheal disease outbreaks: yes, there is a positive change. J Fam Med Prim Care 2019;8:1202–8.
43. Mahajan K, Sekhri S. Access to toilets and violence against women. New Delhi, India: Working Papers 44, Department of Economics, Ashoka University; 2020.
44. Barnard S, Routray P, Majorin F, Peletz R, Boisson S, Sinha A, Clasen T. Impact of Indian Total Sanitation Campaign on latrine coverage and use: a cross-sectional study in Orissa three years following programme implementation. PLoS One 2013;8:e71438.
45. Hueso A, Bell B. An untold story of policy failure: the Total Sanitation Campaign in India. Water Policy 2013;15:1001–17.
46. Ministry of Drinking Water and Sanitation. Government of India. Rajya Sabha Session—245 Unstarred Question no. 995; source: IMIS of SBM(G). State/UT-wise individual household latrines constructed under Swachh Bharat Mission (Gramin) [SBM(G)] from 2014–15 to 2016–17 [Internet]. 2019 [cited June 3, 2021]. Available from: https://data.gov.in/resources/stateut-wise-individual-household-latrines-constructed-under-swachh-bharat-mission-gramin
47. Reproductive & Child Health Project. District Level Household & Facility Survey (DLHS-4) [Internet]. 2014 [cited June 3, 2021]. Available from: http://rchiips.org/DLHS-4.html
48. Office of the Registrar General and Census Commissioner (India). Annual Health Survey (AHS) India [Internet]. 2014 [cited June 3, 2021]. Available from: https://www.censusindia.gov.in/2011census/hh-series/cab.html.
49. International Institute for Population Sciences (IIPS) and ICF. National Family Health Survey (NFHS-4), 2015–16 [Internet]. Mumbai: IIPS; 2017 [cited June 3, 2021]. Available from: https://dhsprogram.com/pubs/pdf/FR339/FR339.pdf.
50. Jung L, De Neve J-W, Chen S, Manne-Goehler J, Jaacks LM, Corsi DJ, Awasthi A, Subramanian S V, Vollmer S, Bärnighausen T, et al. Nationally representative household survey data for studying the interaction between district-level development and individual-level socioeconomic gradients of cardiovascular disease risk factors in India. Data Br 2019;27:104486.

51. Geldsetzer P, Manne-Goehler J, Theilmann M, Davies JI, Awasthi A, Danaei G, Gaziano TA, Vollmer S, Jaacks LM, Bärnighausen T, et al. Geographic and sociodemographic variation of cardiovascular disease risk in India: a cross-sectional study of 797,540 adults. PLoS Med 2018;15:e1002581.
52. Dandona R, Pandey A, Dandona L. A review of national health surveys in India. Bull World Health Organ 2016;94:286.
53. WHO. Nutrition Landscape Information System (NLIS) Country Profile Indicators: Interpretation Guide. Geneva (Switzerland): World Health Organization; 2019; Available from: https://www.who.int/nutrition/nlis_interpretation_guide.pdf
54. WHO. The WHO child growth standards [Internet]. 2019 [cited June 3, 2021]. Available from: https://www.who.int/childgrowth/standards/en/.
55. Office of the Registrar General & Census Commissioner, India. Government of India Census Terms Ministry of Home Affairs [Internet]. 2011[cited June 3, 2021]. Available from: http://censusindia.gov.in/Data_Products/Library/Indian_perceptive_link/Census_Terms_link/censusterms.html
56. Kapur A, Iyer S. Swachh Bharat Mission SBM (Gramin) budget briefs 2015–16. Budg Briefs [Internet]. 2015;7 [cited June 3, 2021]. Available from: https://ssrn.com/abstract=2574160.
57. Ministry of Drinking Water and Sanitation. Government of India. State/UT-wise individual household latrines constructed under Swachh Bharat Mission Gramin (SBM-G) from 2014–15 to 2016–17 [Internet]. [Rajya Sabha Session 245] cited June 3, 2021. Available from: https://data.gov.in/resources/stateut-wise-individual-household-latrines-constructed-under-swachh-bharat-mission-gramin.
58. Ministry of Drinking Water and Sanitation. Government of India. Unstarred Question No. 2423. State/UT-wise individual household latrines constructed under Nirmal Bharat Abhiyan (NBA)-2012 [Internet]. Rajya Sabha Session 237 [cited June 3, 2021]. Available from: https://data.gov.in/resources/stateut-wise-individual-household-latrines-constructed-under-nirmal-bharat-abhiyannba-2012.
59. Meyer BD. Natural and quasi-experiments in economics. J Bus Econ Stat 1995;13:151–61.
60. Filmer D, Pritchett LH. Estimating wealth effects without expenditure data—or tears: an application to educational enrollments in states of India. Demography 2001;38:115–32.
61. UNICEF. Improving child nutrition: the achievable imperative for global progress [Internet]. 2013[cited June 3, 2021]. Available from: https://www.unicef.org/gambia/Improving_Child_Nutrition_-_the_achievable_imperative_for_global_progress.pdf
62. Johri M, Subramanian S V, Koné GK, Dudeja S, Chandra D, Minoyan N, Sylvestre M-P, Pahwa S. Maternal health literacy is associated with early childhood nutritional status in India. J Nutr 2016;146:1402–10.
63. Chakrabarti S, Singh P, Bruckner T. Association of poor sanitation with growth measurements among children in India. JAMA Network Open 2020;3:e202791.
64. StataCorp. Stata base reference manual release 14. Margins. Stata Statistical Software: Release 14. College Station (TX): StataCorp LP; 2015.
65. Headey D, Hoddinott J, Ali D, Tesfaye R, Dereje M. The other Asian enigma: explaining the rapid reduction of undernutrition in Bangladesh. World Dev 2015;66:749–61.
66. Jung YT, Lou W, Cheng Y. Exposure–response relationship of neighbourhood sanitation and children's diarrhoea. Trop Med Int Heal 2017;22:857–65.
67. Jayachandran S, Pande R. Why are Indian children so short? The role of birth order and son preference. Am Econ Rev 2017;107:2600–29.
68. Alderman H, Headey D. The timing of growth faltering has important implications for observational analyses of the underlying determinants of nutrition outcomes. PLoS One 2018;13:e0195904.
69. Leroy JL, Frongillo EA, Dewan P, Black MM, Waterland RA. Can children catch up from the consequences of undernourishment? Evidence from child linear growth, developmental epigenetics, and brain and neurocognitive development. Adv Nutr 2020;11:1032–41.
70. Handley MA, Lyles CR, McCulloch C, Cattamanchi A. Selecting and improving quasi-experimental designs in effectiveness and implementation research. Annu Rev Public Health 2018;39:5–25.
71. VanderWeele TJ, Ding P. Sensitivity analysis in observational research: introducing the E-value. Ann Intern Med 2017;167:268–74.
72. Corsi DJ, Mejía-Guevara I, Subramanian SV. Risk factors for chronic undernutrition among children in India: estimating relative importance, population attributable risk and fractions. Soc Sci Med 2016;157: 165–85.
73. Kim R, Mejia-Guevara I, Corsi DJ, Aguayo VM, Subramanian SV. Relative importance of 13 correlates of child stunting in South Asia: insights from nationally representative data from Afghanistan, Bangladesh, India, Nepal, and Pakistan. Soc Sci Med 2017;187: 144–54.
74. Lundeen EA, Stein AD, Adair LS, Behrman JR, Bhargava SK, Dearden KA, Gigante D, Norris SA, Richter LM, Fall CHD. Height-for-age z scores increase despite increasing height deficits among children in 5 developing countries. Am J Clin Nutr 2014;100:821–5.
75. Indian Institute for Population Sciences. National Family Health Survey (NFHS-5) [Internet]. Ministry of Health and Family Welfare, Government of India; 2020 [cited June 3, 2021]. Available from: http://rchiips.org/NFHS/NFHS-5_FCTS/NFHS-5 State Factsheet Compendium_Phase-I.pdf.
76. The World Bank. GDP growth (annual %)—India [Internet]. 2021 [cited June 3, 2021]. Available from: https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG?end=2019&locations=IN&start=2014
77. Menon P, Nguyen P, Avula R, Sarswat E. New India national family health survey data shows worrying trends on anemia, overweight [Internet]. International Food Policy Research Institute (IFPRI); 2021 [cited June 3, 2021]. Available from: https://www.ifpri.org/blog/new-india-national-family-health-survey-data-shows-worrying-trends-anemia-overweight
78. Zhu H, Gupta A, Majumder B, Steinbach S. Macro shocks and micro woes: short-term effects of India's demonetization on the poor [Internet]. 2017. Available at SSRN: https://ssrn.com/abstract=3001396 or http://dx.doi.org/10.2139/ssrn.3001396.
79. Wadhwa S. Impact of demonetization on household consumption in India [Internet]. 2019 [cited June 3, 2021]. Available from: https://sagarwadhwa.com/Files/sagar_demonetization_latest.pdf.
80. Vyas S, Srivastav N, Mary D, Goel N, Srinivasan S, Tannirkulam A, Ban R, Spears D, Coffey D. Measuring open defecation in India using survey questions: evidence from a randomised survey experiment. BMJ Open 2019;9:e030152.
81. Coffey D, Spears D. Where India goes: abandoned toilets, stunted development and the costs of caste. New Delhi, India: HarperCollins; 2017.
82. Briend A, Khara T, Dolan C. Wasting and stunting—similarities and differences: policy and programmatic implications. Food Nutr Bull 2015;36:S15–23.
83. Richard SA, Black RE, Checkley W. Revisiting the relationship of weight and height in early childhood. Adv Nutr 2012;3:250–4.