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Child Malnutrition & Mortality: Role of Sanitation & Sewage Systems

by

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Abstract

Child malnutrition and mortality are critical public health challenges in India, exacerbated by inadequate sanitation infrastructure. This study examines the effects of sanitation and sewage systems on malnutrition indicators (stunting, underweight, and wasting) and child mortality in India. Utilizing data from the NFHS-4 and NFHS-5 across 28 states and one union territory, the analysis investigates how access to improved sanitation, specifically private and shared toilets with sanitation and sewage systems, influences child health outcomes and indirectly impacts mortality through malnutrition.

The findings demonstrate that use of toilet facilities significantly reduces stunting and underweight prevalence, with shared toilets having a greater effect than private toilets. In contrast, open defecation is associated with increased malnutrition, particularly affecting stunted and underweight children under five. The study also highlights female education as a vital factor in reducing child mortality, suggesting that maternal education contributes positively to child health and sanitation awareness. Additionally, the indirect pathway of sanitation's impact on mortality—through reduced malnutrition—emphasizes the broader public health benefits of sanitation improvements.

These results underscore the potential of sanitation initiatives, such as the Swachh Bharat Mission, to improve child health by reducing malnutrition and mortality risks. The study calls for integrated public health policies focusing on sanitation infrastructure, public health education, and female education to address malnutrition and mortality comprehensively. This research provides evidence supporting policies that prioritize sanitation improvements as a foundational element in enhancing child health outcomes in India.

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1. Introduction

The Indian constitution assigns different government functions to different levels of Government based largely on the "principle of subsidiarity," as understood at the time of framing of the constitution. Consequently, health, education & other social services were put on the States list of the constitution. Education was moved to the concurrent list during the 1970s, but health remains the responsibility of the States. Starting in 1950s Primary health centers (PHCs) started to be constructed in States like Delhi, West Bengal and Tamil Nadu, followed by Maharashtra & others in the 1960s & 1970s. In 1973 there were only 5250 PHCs for about 600 million population. These increased to 9134 by 1980, with 810 Community health Centers being added (CHCs) at a higher level, to support them. The number of PHCs per 100,000 population was 2.03 in 2004, 1.91 in 2014 and 2.19 in 2022, while the number of CHCs per 100,000 population were 0.29 in 2004, 0.41 in 2014 and 0.43 in 2022. The focus of these efforts was an improvement of health services available to rural and poor households.

Public health efforts, like universal vaccination, were not a part of the everyday mandate of these centers. The challenge of communicable diseases was addressed through specific vaccination campaigns, like the National Smallpox Eradication Program (1962, 1964), Expanded Program on Immunization (1978) and Universal Immunization program (1985). The Universal Immunization program was launched in 31 districts of India and in 1990 it was universalized to cover the entire country. Starting 1992-93 the basic vaccination coverage for children has more than doubled from 35.4% to 77% in 2019-21 and the percentage of children who received no vaccinations, declined from 30% to 3.6%.[2]

Public health issues like clean drinking water, sewage and sanitation systems, solid waste collection & recycling did not receive much political attention during the first 50 years of India's independence. For instance, piped water (private & public taps) was only available to 38.7% of households in 1998-99 and had improved to 42% by 2005. Worse, 64% had no toilet facility in 1998-99. This reduced to 55.3% by 2005-06. The SwaJal Dhara mission was launched in 2002 to give communities access to better quality drinking water. It should be noted that the issue of clean drinking water is intimately linked with the issue of contamination of water sources with fecal matter (Kremer et al, 2023)

The Total sanitation campaign was launched in 2002. With 55.3% still having no toilet facility in 2005-06, this was modified into the Nirmal Bharat Abhiyan in 2012. The Swachh Bharat mission to eliminate open defecation and improve waste management was launched in 2014. This reduced the percentage of households with no toilet facility from 38.9% in 2015-16 to 19.4% by 2019-21 and the percentage of population that defecates in the open has gone down from 39.8% in 2015-16 to 19.3% in 2019-21.

The importance of Sanitation, modern sewage systems and solid & liquid waste disposal, arises from its hypothesized link to a medical condition, first described as *Tropical enteropathy*. Medical researchers started suspecting such a condition in the late 1960s (Cook et al.,1969; Colwell et al.,1968; Garcia, 1968) and 1970s (Baker & Mathen ,1972; Lindenbaum, 1973), which involved chronic histological changes in the individuals living in the tropical areas. It

[2] Data from NFHS 1 to NFHS 5.

was not until the 1980s that medical researchers began to identify an *asymptomatic* condition related to the upper alimentary canal (jejune), which did not display any of the symptoms of known diseases like diarrhea and tropical sprue and called it *Environmental Enteropathy* (Fagundes-Neto et al.,1984). Lunn (1991) linked *Environmental Enteropathy* (EE) with Lactulose-Mannitol (L:M) ratio and showed that abnormal L:M ratio could explain half the impaired growth in a group of Gambian children (Lunn PG et al., 1991). Lin et al. (2013) also linked Environmental Enteropathy with the L:M ratio and showed that Bangladeshi children, with low L-M ratios, in clean environment (drinking water, sanitation, handwashing) attained higher "linear growth" compared to children living in environmentally contaminated households.

The issue of EE lay somewhat dormant in the medical literature for another decade (Korpe and Petri, 2012). In 2013 a group of 18 researchers (Keusch et al., 2013) proposed the term *Environmental Enteric Dysfunction* (EED) as an alternative to the term Environmental Enteropathy. To quote them, "These alterations (in mucosal architecture including reduced enterocyte mass and evidence of immune activation and inflammation in the mucosa) appear to be the result of factors of uncertain nature in the environment and may be a cause of growth faltering and stunting in young children. For these reasons, this constellation of findings is being referred to as environmental enteropathy, or as we propose herein, environmental enteric dysfunction".

Environmental Enteric Dysfunction (EED) is now known to occur, in low and middle-income countries, in areas characterized by relatively high levels of Open defecation and/or poor sanitation facilities. Constant exposure to intestinal pathogens through faecal contamination leads to "inflammation, reduced absorptive capacity and reduced barrier function in the small intestine" (Crane et al., 2015). Socio-economic studies have therefore used the per cent of population practicing open defection or the per cent of households with unimproved toilet facilities as indicators of unsanitary conditions, to measure their impact on child malnutrition (implicitly via EED). Other indicators of sanitary environment and practices include availability of clean drinking water and prevalence of hand washing.

Child malnutrition is conventionally measured by three indicators, viz., *stunting* (low height-for-age), *underweight* (low weight-for-age) and *wasting* (low weight-for-height). According to the World Health Organization, globally, 149 million children were estimated to be stunted and 45 million were estimated to be wasted as of 2022. Of these, India accounted for 24.6% of all stunted and 8.8% of all wasted children (World health Organization, 2023). Basic sanitation services such as private toilets or latrines are still out of reach of over 1.5 billion people globally and "419 million of these still (in 2022) defecate in the open, for example in gutters, behind bushes or open water bodies" (WHO)[3].

This paper focuses on the impact of sanitation & sewage systems on under-five child malnutrition and child mortality. While it has often been believed that it is the lack of adequate nutrition or poverty-induced undernutrition that leads to anthropometric failure in children, many studies have identified open defecation or a lack of (improved) sanitation facility as a

[3] https://www.who.int/news-room/fact-sheets/detail/sanitation

cause of child malnutrition. We investigate the link between different qualities of sanitary-sewage systems and stunting, underweight and mortality in children less than 5 years old, across all Indian states.

Section 2 reviews the literature. Subsections focus on literature on open defecation, sanitation & toilets and drinking water, followed by a review on child mortality and sanitation. The section ends by pointing out the limitations of the literature this study aims to overcome. Section 3 outlines the approach of the study, and the data used to carry out the analysis. Section 4 presents the methodology, followed by the estimation results and discussion in section 5. Section 6 reviews the outcomes of the Swachh Bharat Mission and Beti Bachao, Beti Padhao scheme and section 7 concludes the study and draws some implications for public health policy.

2. Literature Review

Basic sanitation, clean drinking water and hygiene are practices fundamental to human development, human health and well-being[4]. Absence of sanitation and good hygiene can lead to adverse health outcomes- malnutrition, especially for children. While inadequate nutrition has been considered as a cause of malnutrition (Gulati, 2010; Ijarotimi, 2013) in children under the age of 5 years, the prevalence of open defecation has been recognized as a major determinant of stunting in children under the age of 5 years (Spears, 2013; Spears et al., 2013). The adverse effect of stunting is especially prevalent for areas where the population defecating in the open per square km is higher (Spears et al., 2013) or where everyone defecates in the open (Vyas et al., 2016; Cameron et al., 2020).

If open defecation is widespread, more and more areas will contain faecal matter, resulting in more children being exposed to protozoal enteric infections of children who play in these area. These protozoal pathogens cause gastrointestinal diseases that reduce the nutrient absorptive power of the stomach and even good nutrition is not enough to prevent children from malnourishment (Virmani, 2007; Virmani, 2012). While Lancet Maternal and Child Undernutrition Series noted that 99% sanitation coverage resulted in diarrhoea being reduced by 30% and in turn prevalence of stunting going down by only 2.4%, Humphrey (2009) pointed out that the Lancet study underestimated the effect of sanitation and hygiene on growth because the effect was modelled only through diarrhoea. Humphrey emphasized that it was in fact tropical enteropathy that resulted in child undernutrition, and that providing toilets and promoting handwashing after faecal contact could prevent tropical enteropathy and its ill effects on growth.

Studies find that a reduction in open defecation, by increasing sanitation coverage, leads to increased child growth outcomes (Headey et al., 2014; Hammer and Spears, 2016; Augsburg and Rodriguez-Lesmes, 2018) or a reduction in stunting (Girma et al., 2021; Singh et al., 2021). For children in the age group of 0-2 years, who are too small to use a toilet, children's contact with older family members who practice open defecation and are at risk of direct or indirect (through flies) contact to faecal contamination, may expose children at home to faecal

[4] https://www.who.int/india/health-topics/water-sanitation-and-hygiene-wash

contamination (Berendes et al., 2017). In this context, personal hygiene practices such as handwashing may thus be associated with stunting in households with access to toilet facility or piped water (Rah et al.,2015).

Weaver et al (2024) undertook a maternal cash transfer experimental study (RCT) to investigate the effect of increase in income, and consequent increase in nutritional intake including caloric consumption. They showed that "anthropometric outcomes of young children did not improve when the sanitation environment was poor. Child anthropometric indicators improved only in areas with low rates of open defecation".

Sewage, Sanitation, Toilets

Many studies have found that improved sanitation (facility) or access to (improved) toilet facility, can result in significantly lower likelihood of stunting in children, compared to unimproved sanitation facilities (Aheto et al., 2015; Dwivedi et al., 2018; Rah et al., 2020, Das et al. ,2022) or open defecation (Rah et al., 2015; Rahman et al., 2020). However, the impact varies across studies; Rah et al. (2020) finds the odds of stunting reduce by 29% for Indonesian children, Dwivedi et al. (2018) find the odds reducing by only 3% for Indian children, Rah et al. (2015) find 16-39% reduction in odds of stunting in rural India, and Rahman et al. (2020) find that chances of child stunting and underweight decline by 13% and 28% in Indonesia. Das et al. (2022) find the odds of stunting increase 10% with unimproved sanitation in India.

Khan et al. (2021) find the odds of stunting (underweight) higher by 81% (63%) for open defecation & 60% (51%) higher for unimproved sanitation (relative to piped sewerage network), in Pakistan.[5] Sahiledengle et al. (2022) find higher odds of child stunting in children with unimproved toilet facilities (20%), and open defecation (29%), relative to improved sanitation. They find no association between improved sanitation and child wasting. In contrast, van Cooten et al. (2018) find that improved toilet facility lowers the odds of children being wasted (over unimproved) and Aheto et al (2015) finds that the probabilities of wasting increased for no toilet facilities (relative to pit/flush toilet). Das et al. (2022) find that chances of wasting and underweight increased by 10% with unimproved sanitation. Virmani (2007) finds household access to a toilet plays a significant role in explaining inter-state variations in underweight children.

Drinking Water

The impact of access to improved drinking water sources is found to be mixed. Virmani (2012) finds improved sources of water to be significant in explaining cross-country variation in weight-for-age indicator (under-weight). Batool et al (2023) finds hand pumps and tank water to be significant (at 10%) negative determinants of stunting. Saheed et al. (2021) find a highly significant association of underweight and stunting with water in Pakistan. Das et al. (2022) did not find any significant effect of improved drinking water sources on stunting, wasting or underweight. Headey et al. (2014) and Rah et al. (2020) find no effect of piped drinking water

[5] The level of significance is 5% & 10%. These odds of stunting/underweight are estimated in separate logistics regressions, and are even higher for flush to pit latrine. It's possible that pit latrines are contaminating the ground water, which is obtained with hand pumps.

on growth outcomes, while Lauer et al (2018) finds no association between unimproved water and stunting risk.

Mortality

Under-five mortality, which is defined as the number of deaths per 1000 live births for children less than 5 years old, has also been found to be associated with lack of sanitation facility in households (Semba et al., 2011). Günther and Fink (2011), using logistic regressions on data from 38 surveys from 30 countries, finds the effect of private flush toilet and private piped water connection to be highly significant in reducing child mortality. This can reduce the odds of early child mortality by about 8% each. Children living in households with improved sanitation facilities have a 20% lower mortality risk than those living in households with unimproved sanitation facilities (Dwivedi et al., 2018). Chakrabarti et al. (2024) find that toilet construction under the Swachh Bharat Mission, increased access to toilets in India, and reduced infant and child mortality.

Education, especially of females have been considered essential in explaining lower malnutrition in children (Virmani, 2007) by helping spread knowledge and awareness about "personal hygiene, sanitation and nutrition" (Virmani, 2012). Children whose mothers have 10 or more years of formal education are 45% less likely to be stunted compared to those whose mothers have no formal education. (Rahman et al., 2020).

The review identifies following limitations which our paper seeks to overcome. One, the importance of "Sanitation and Sewer systems (SS)" which lie behind the "improved" sanitation/toilets that the literature has investigated. Two, the important distinction between unshared (private) toilets and shared toilets, which is of relevance in India. Three, our study focuses on the effect of sanitation on both child stunting and underweight, compared to most which focus only on stunting. We also investigate the effect on wasting. Four, we account for the fact that open defecation itself is dependent on availability of sanitation facility. Finally, we investigate the effect of malnutrition on child mortality, besides the effect of sanitation on child mortality.

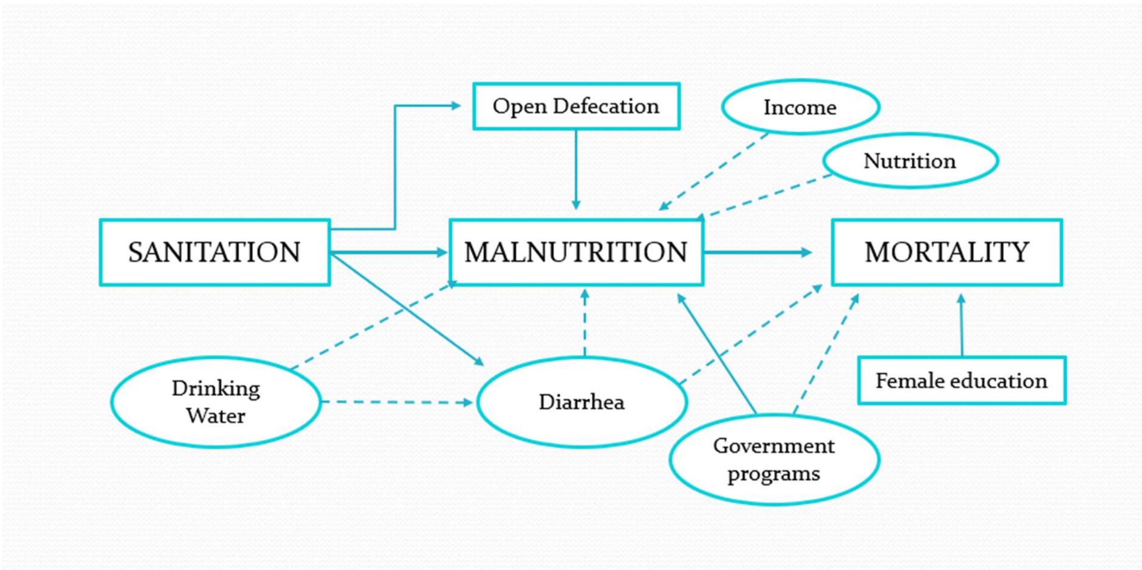
3. Approach and Data

3.1 Approach of the study

This paper examines the critical role of environmental enteric dysfunction (EED) in child malnutrition. Specifically, it highlights how public health externalities, such as open defecation, and the availability of proper sanitation facilities (both public and private), have a greater impact on child malnutrition than factors related solely to individual health, such as access to nutritional food and supplements. Poor hygiene practices and open defecation can expose children to enteric pathogens, leading to EED and ultimately contributing to malnutrition.

Improving sanitation by ensuring access to toilets with well-managed sewage systems can significantly reduce these negative externalities by limiting the likelihood of open defecation. Consequently, the availability of both public and private sanitation infrastructure plays a crucial role in addressing child malnutrition. Since malnutrition affects critical growth parameters like height and weight and can even lead to mortality in children under the age of five, it is essential to address the sanitation-malnutrition connection comprehensively (figure 1).

Figure 1 :Model Framework



Poor sanitation not only exacerbates malnutrition but can also contributes to increased child mortality through its indirect impact on nutritional health. Public health education, alongside broader educational initiatives, can raise awareness about the importance of sanitation, potentially leading to a reduction in child mortality rates (figure 1).

While the role of drinking water in gastrointestinal diseases like diarrhoea is acknowledged, its relationship with malnutrition remains mixed, possibly due to varying levels of faecal contamination in water sources. Moreover, diarrhoea itself may have weaker links to malnutrition and child mortality, as it does not fundamentally alter gut function.

Although traditional socio-economic factors such as income (a measure of poverty) and access to nutrition influence malnutrition, their effects may be limited in environments where children are exposed to poor sanitation conditions. Government programs, such as the Universal Immunization Programme. Total Sanitation Campaign, and Swachh Bharat Mission, have been the most effective interventions in improving public health outcomes, particularly through the construction of toilets. Meanwhile, health-focused programs like the Integrated Child Development Services have been more effective in addressing individual health concerns.

Figure 1 summarises the approach of our study. Solid arrows indicate strong links between variables, based on our belief that these relationships are particularly significant. Dashed arrows, on the other hand, represent weaker links, reflecting our view that these connections are less important in explaining inter-State variations in child malnutrition. In the following sub-section, we outline the survey data, the available variables and the variables we use in estimating the model (presented in a subsequent sub-section) and testing the impact of variables proposed by other researchers.

3.2 Data

Our study uses a two-period panel data of all 28 Indian States and 1 UT (J&K) from NFHS 4 (2015-16) and NFHS 5 (2019-21).[6] All variables in the malnutrition estimation are taken from these surveys, except per capita NSDP.

Child malnutrition in children less than 5 years old, is measured by 3 indices of physical growth-stunting, underweight and wasted to describe the nutritional status of children. A child is said to be stunted when the "child's height-for-age Z score is less than -2 standard deviations (SD) from the median reference population" (NFHS 3 India, 2005-06). This index is an indicator of "linear growth retardation and growth deficits". A stunted child is considered short for their age. A child is said to be underweight i.e. suffering from "acute and chronic malnutrition if their weight-for-age is below minus 2 standard deviations from the median reference population. A child whose weight-for-height Z score is less than -2 SD from the median reference population are thin (wasted) for their height and are acutely malnourished" (NFHS 3 India, 2005-06). These are our key dependent variables.

In India, toilet facilities may be private or shared among households, with the latter including public toilets, with the Flush or pour flush being considered the best. The quality of sanitation depends on both the toilet facility and the method or system by which the faecal matter is disposed. The latter include piped sewer system, septic tank or pit latrine.[7] Inferior systems include pit latrine with slab, open pit, dry toilet, ventilated improved pit (VIP) latrine/biogas latrine, and twin pit or composting toilet. In this study, we use two types of toilets, with better quality sanitation and sewage systems (SS) in India.

1. Improved, not shared facility, with flush/pour flush to piped sewer system, septic tank, or pit latrine (Private toilet, SS)
2. Shared facility, with flush/pour flush to piped sewer system, septic tank, or pit latrine (Shared toilet, SS)[8].

Open defecation is the variable defined in the survey as, "No facility/ uses open spaces/ field" The values indicate the percentage of de jure population that use these facilities.

Income per capita, a measure of economic well-being and an indicator of absolute poverty is also tested as a determinant of malnutrition. Higher poverty may lead to access to poor quality of food, no personal toilets and thus poor anthropometric measures among children. As consumption expenditure surveys are only available for 2011-12 and 2022-23, we cannot calculate poverty for other years. We therefore use the Per capita Net State Domestic Product (constant 2011-12 prices) as an indicator of income per capita. This data is from the "Database on Indian economy," Reserve Bank of India.

To measure contaminated water as a cause of malnutrition, we use the variable "unimproved source of drinking water" which include unprotected dug well, unprotected spring and surface

[6] Because of COVID pandemic, the NFHS survey was done in two phases. Phase 1 in 2019-20 covered 17 States & 5 UTs, and phase 2 in 2020-21 covered 11 States & 3 UTs

[7] As the NFHS data for States does not have separate data for piped sewer system, septic tanks and pit latrines, we leave this for a subsequent study.

[8] Shared sanitation facility is sanitation facility used by 2 or more households

water. Improved sources of drinking water include piped water into dwellings/yard/plot, public tap/standpipe, tube well or bore hole & others. We do not have information on the degree of contamination of the latter water sources.

To measure nutritional intake in children through food, we use micronutrient intake among children. Data on percentage of children who consumed Vitamin A rich foods and iron rich foods in the last 24 hours is calculated and used for this purpose. The age group for which data is available in both NFHS 4 and NFHS 5 is 9-23 months. Since the aggregate percentage for this age group was not given, it was calculated for the purpose of the study. Along with this percentage of children given complementary foods (solids and semi-solids) after 6 months of breastfeeding and up to 23 months (i.e. 6-23 months old children) is also calculated and used as a measure of nutrition. Any children who got complementary food was classified in that category as long as they were breastfeeding as well.

Breast feeding has been used in the literature as an indicator of nutrition quality for infants. In the presence of contaminated water use supplementary feed could also convey the pathogens in water to the infant. The percentage of children less than 2 years old (0-23 months) exclusively breastfed is used in the study an indicator of these two factors.

To measure the effect of sanitation on child mortality, we use child mortality data from the Statistical Appendix of the Economic Survey of 2023-24. Child mortality is defined as "under five mortality (per 1000 live births)". Apart from this, female education is also used as a determinant of child mortality. The percentage of females with more than 10 years of schooling is used as a proxy for female education.

To measure the effect of sanitation on diarrhoea, the percentage of children under 5 years with diarrhoea is calculated. These children had diarrhoea in the two weeks preceding the survey.

To test for the effect of vaccination on child mortality, we use the per cent of children, given basic vaccination. Basic vaccinations include BCG, MCV/Measles/MMR/MR, and three doses each of DPT/Penta and polio vaccine (excluding polio vaccine given at birth). We also test for the effect of the integrated Child Development Services (ICDS) programme on child mortality, by using the number of Anganwadi workers as variables explaining child mortality. This data is again sourced from NFHS State reports. The source of Anganwadi workers is IndiaStat.

3.3 Descriptive Statistics and Graphs

It is useful to start by looking at the sample statistics for the two-period panel data of 28 Indian states and one UT used for estimation of our model (figure 1). Table 1 presents the statistics for 2019-21, while table 2 shows the changes between 2015-16 and 2019-21.

The maximum value of per capita income across the states and UT, measured by per capita net state domestic product was equal to INR 3,10,000 whereas the minimum value for the same was INR 29,798 in 2019-21. The mean income increased by INR 18122 over a period of 4 years from 2015-16 to 2019-21, reaching INR 1,10,000 (first row in tables 1 and 2).

Table 1: Sample Statistics for the 28 State plus 1 UT 2019-21

Variable	n	Mean	S.D.	Median	Min	Max
Per Capita Net State Dom Product	29	110000	62983	110000	29798	310000
Stunted children (%)	29	31.8	6.0	31.8	22.3	46.5
Wasted children (%)	29	17.3	4.4	18.1	9.8	25.6
Underweight children (%)	29	26.7	8.0	26.9	12.7	41
Private toilet, SS (%)	29	66.2	17.4	68.4	30.1	93.8
Shared toilet, SS (%)	29	7.0	4.0	6.7	0.5	20
Unimproved sanitation (%)	29	3.8	4.08	2.6	0.6	17.4
Open Defecation (%)	29	11.9	11.3	6.9	0.1	38.1
Child mortality	29	33.3	13.3	33	5.2	59.8
Female schooling	29	44.2	13.0	44.4	23.2	77

The mean percent stunted children in 2019-21 was 31.8%, 5% points higher than the mean percentage of underweight children at 26.7%. Although the change in average stunted and underweight children was a mere -1.2 and -1.7 percentage points, some states showed significant improvements in their child malnutrition figures. For instance, Rajasthan and Sikkim reduced stunting by 7.3 percentage points, Uttar Pradesh by 6.6% and Uttarakhand and Haryana by 6.5 percentage points. The decline in underweight children on the other hand was more pronounced in the States of Rajasthan (-9.1%), Jharkhand (-8.4%), Haryana (-7.9%) and Uttar Pradesh (-7.4%)[9].

The mean percentage of population using sanitation and sewage facility in their homes (Private toilet, SS) reached 66.2% in 2019-21, an increase of 15.8 percentage points on average over 4 years. This positive change was driven by Chhattisgarh (31%), Meghalaya (30.2%), Odisha (27.8%) and Madhya Pradesh (25%).[10]

Unimproved sanitation, which is better than open defecation, but inferior in quality to SS-private or Shared toilet, SS, also saw a significant dip of 28.8 percentage point in its mean value. The states of Jharkhand (-66.3%), Odisha (-65.3%), Bihar (-65.1%), Madhya Pradesh (-56.7%), Chhattisgarh (-55.7%) and Uttar Pradesh (-53.8%) fuelled this change in unimproved sanitation. Open defecation declined on average by 14.2 percentage points during 2015-16 to 2019-21. This reduction in open defecation was higher in the states of Chhattisgarh (-43.3%), Jharkhand (-37%), MP (-32.2%), Odisha (-31.6%) and UP (31.7%).

Child mortality also saw a small decline of 7.1 deaths per 1000 live births on average between 2015-16 and 2019-21 (table 2). The mean percentage of females with more than 10 years of schooling went up to 44.25%, a change of 6 percentage points.

[9] Numbers in parenthesis are percentage points

[10] Shared toilets were used on average by 7% of the population in 2019-21. This represented a marginal decline of -0.6% in the mean across states, since 2015-16.

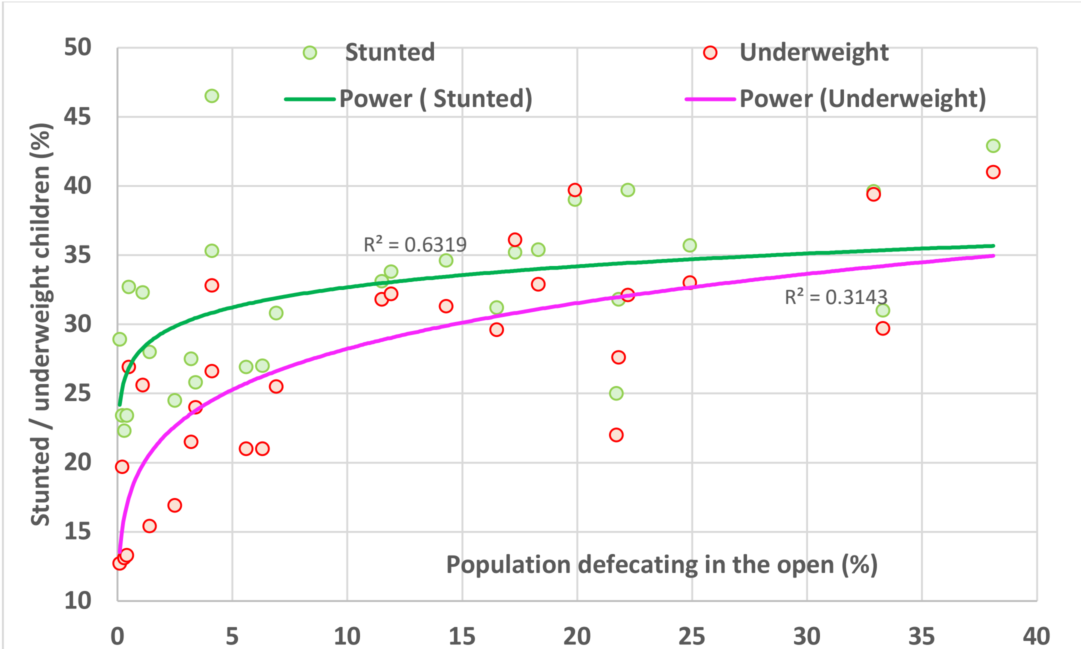
Table 2: Change in variables between 2015-16 and 2019-21

Variable	n	Change in mean	Change in S.D.	Change in median	Change in min value	Change in max value
Per Capita Net State Dom Prd	29	18122	10488	21391	5734	30000
Stunted children (%)	29	-1.2	-1.4	-0.7	2.6	-1.8
Wasted children (%)	29	-1.2	-1.2	0.0	3.7	-3.4
Underweight children (%)	29	-1.7	-1.8	-2.0	0.7	-6.8
Private toilet, SS (%)	29	15.8	-2.2	18.6	6.7	5.2
Shared toilet, SS (%)	29	-0.6	-0.1	0.0	-0.3	0.6
Unimproved sanitation (%)	29	-28.8	-16.4	-29.5	-0.4	-53.1
Open Defecation (%)	29	-14.2	-11.3	-13.9	-0.1	-31.8
Child mortality	29	-7.1	-1.9	-4.6	-1.9	-18.3
Female schooling	29	6.0	0.6	10.1	0.4	4.8

The socio-economic literature on child malnutrition has identified open defecation as a culprit for malnutrition in children. Thus, we start by looking at the traditionally postulated positive link between open defecation and malnutrition in children. States that have higher percentage of population defecating in the open, have a higher percentage of stunted and underweight children less than 5 years old (figure 2). The effect of open defecation on stunting/underweight appears to be higher below 5%-10% OD level, and somewhat less beyond this level.

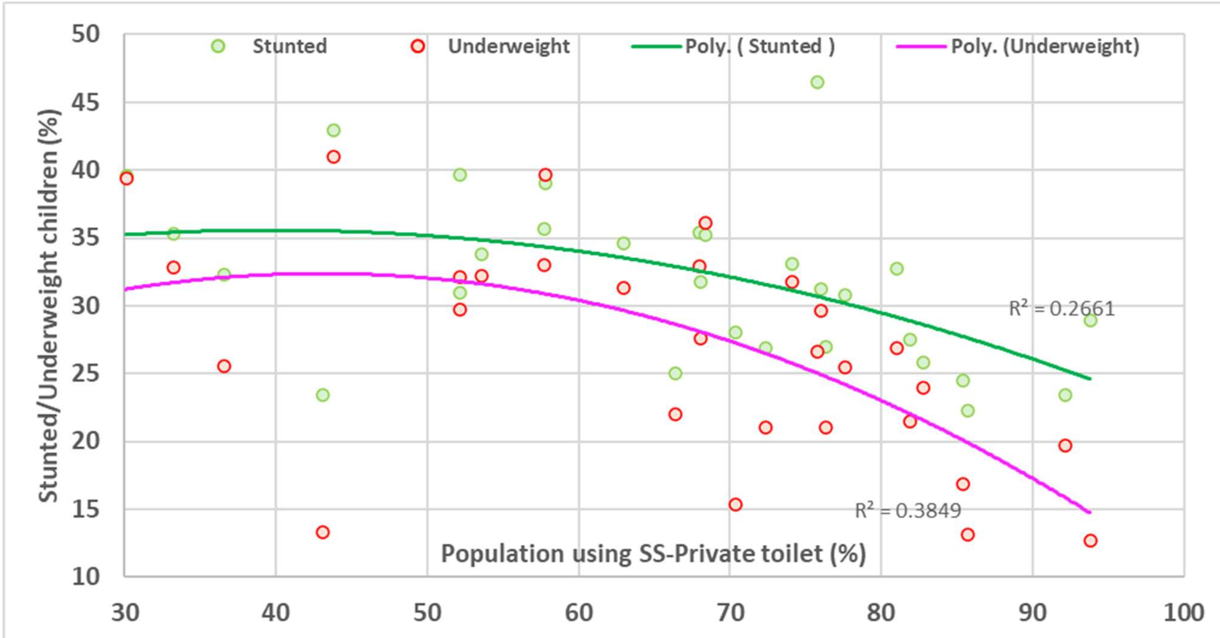
The prevalence of open defecation itself is partly due to a lack of improved sanitation facilities available to the people. This points to lack of sanitation and sewage as a fundamental factor in the problem the problem of children stunting and underweight.

Figure 2: Malnutrition and Open defecation across States



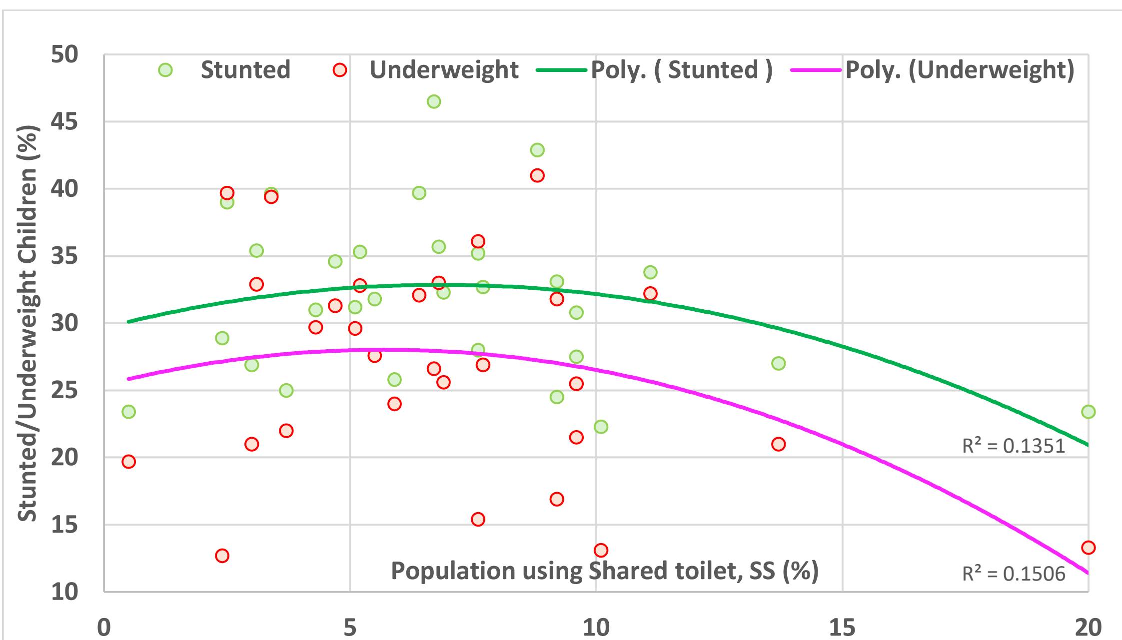
Figures 3 and 4 directly depict the relationship between child malnutrition (stunting and wasting) and the two types of toilets with improved sanitation and sewage, private & shared respectively. Figure 3 shows, that as the proportion of population using private toilets with improved sewage system increases, the per cent of stunted children (height-for-age) and underweight children (weight-for-age) declines. The positive effect accelerates beyond a threshold of 55-60%. As States which have crossed this threshold, an increase in private toilets, seems to result in a greater decline in % of stunted and underweight children with each per cent increase in toilet use. The impact is higher for underweight reduction (pink line) than for reduction in stunting (green line).

Figure 3: Malnutrition and Private toilet, SS across States



The States with a higher percentage of population using shared toilets with improved sewage system, have lower levels of child stunting and underweight. The impact of shared toilets in reducing underweight (pink line, fig 4) children seems to be marginally greater than its effect on reducing stunting (green line, fig 4).

Figure 4: Malnutrition and Shared toilets, SS, across States



However, differences between the two figures can be seen from the concentration of a majority of states in the left-middle panel of figure 4 in contrast to figure 3 where states are concentrated in the right-hand panel. Many of the states that use a small percentage of shared toilet with improved sewage system have a relatively higher percentage of stunted and underweight children. This peculiar case could be result of poor maintenance of the shared toilets, for example in slums where a group of households share a common toilet daily. How often those toilets are cleaned or what is the quality of the shared toilet system, is a question that needs to be explored in the future. An alternative explanation of this result may be that a lower percentage of population using shared toilets may be equivalent to higher levels of open defecation or unimproved sanitation in those states. Thus, the interactions between Open defecation, availability of public toilets and private toilets must be accounted for in the estimation of effects.

The correlation matrix (table 3), prima facie gives us a sense of the variables that could be related with the dependent variables, stunted, underweight and wasted children. Open defecation is positively and moderately correlated with stunted children (0.54) and highly correlated with underweight children (0.74), akin to the result that we saw in figure 2.

Table 3: Correlation matrix for variable in 2019-21

Table 3: Correlation Matrix (2019-20)										
	OD	**Unimproved sanitation**	**SS-Private toilet**	**SS-Shared toilet**	**Stunted**	**Underw eight**	**Wasted**	**PCNSDP**	**Child mortality**	**female education**
Open Defecation	1									
Unimproved sanitat	-0.25	1								
SS-Private toilet	-0.51	-0.43	1							
SS-Shared toilet	-0.26	-0.09	-0.11	1						
Stunted children	0.54	0.13	-0.48	-0.22	1					
Underwt children	0.74	0.03	-0.56	-0.29	0.80	1				
Wasted children	0.54	0.19	-0.46	-0.33	0.54	0.86	1			
PCNSDP	-0.36	-0.34	0.59	-0.07	-0.49	-0.31	-0.07	1		
Child mortality	0.56	0.00	-0.58	0.11	0.67	0.57	0.21	-0.65	1	
female education	-0.44	-0.34	0.70	-0.02	-0.63	-0.50	-0.30	0.64	-0.69	1

The correlation between stunting and underweight and private toilets with improved sanitation & sewage systems is -0.48 and -0.56 respectively, and for shared toilets is a weaker -0.22 and -0.3 respectively This suggests that greater use of shared toilets with sanitation and sewage systems, may not reduce stunting and underweight in children less than the increased use of private toilets with improved sanitation and sewage systems.

The corelation between open defecation and Private toilet, SS, is -0.51, consistent with the model framework in figure 1. The population using shared toilets with a sanitation and sewage system is however found to have a lower negative correlation of -0.26 with open defecation, suggesting that open defecation may be reduced by availability of private toilets and less by use of shared toilets.

In addition to this, child mortality is moderately correlated with open defecation (0.56), Private toilet, SS (-0.58) and stunted (0.67) & underweight children 0.57). These correlations (table 3) are also consistent the modelling approach outlined in figure 1.

As mentioned in the literature, public health education through educational programmes on TV, camps, schools, colleges etc., also plays a role in transmitting information to the people, especially females on the importance of sanitation and how to achieve it. If females are educated, they are more likely to listen to programmes and understand it as they are concerned with improving the well-being of their children or are more able to understand any health education being imparted to them. How the recipient absorbs the information may differ depending on the level of their education.

Female education is found to be negatively correlated with stunted (-0.63) and underweight (-0.50) children and positively corelated (0.7) with private toilets, SS. This is consistent with the hypothesis that female education contributes to a reduction in stunted and underweight children, possible through greater care in dealing with child faeces, including its disposal in private toilets, SS.

Although the above correlations point us in the direction of variables that may possibly affect child malnutrition and mortality, a formal model is needed to test and verify these relationships. The next section presents the model and the equations used for testing.

4. Methodology

4.1 Malnutrition

Many studies have emphasized the importance of open defecation on malnutrition. At the core of our model is the effect of sanitation and sewage systems on stunted and underweight children under 5 years old. A lack of sanitation facilities with sewage systems leads to Environmental Enteric Dysfunction in children, a consequence of which is impaired absorption of nutrition in the guts, and negative affect on their height and weight. Availability of private toilets is the commonly used method of measuring sanitation. In urban slums and other congested areas, the availability of shared or public toilets is also very important.

This paper focuses on child stunting and underweight as key indicators of child malnutrition in a comparative, inter -state or cross-country comparative framework. Wasting is a ratio of underweight to stunting at any age, [11] but several studies (Aheto et al., 2015; Khan and Mohanty, 2018; van Cooten et al., 2018; Sahiledengle et al., 2022) have used wasted as a measure of malnutrition, so the paper also investigate the impact of sanitation on wasting in children less than 5 years old. Child malnutrition is hypothesized to be a function of open defecation and toilet.

Child malnutrition=f (Open defecation, Private toilet, SS, Shared toilet, SS,)

Taking account of state fixed effects, the above function can be written in a linear functional form, using a two-period panel data set of 28 Indian States and one UT

[11] As height and weight are both affected by sanitation, the effect of sanitation on wasting (weight/height) will be less pronounced, and more variable/unstable. Wasting is simply the ratio of underweight to stunted. Any change in stunting and underweight both, will not have any major effect on wasting.

$$Y_{it} = \varphi_0 + \varphi_1 * Open\ defecation_{it} + \varphi_2 * Pvt\ toilet_{it} + \varphi_3 * Shared\ toilet_{it} + \sum_{i=1}^{n=29} Si + U_{it}$$
(1')

Where, U_{it} is the error term, t = is either 2015-16 or 2019-21, i = 1...29, represents the States & UT in the data sample. Y is the percentage of stunted, underweight or wasted children under the age of 5 years, Pvt toilet is Private toilet, SS (%), Shared toilet is Shared toilet, SS (%). Private toilet, SS indicates the percentage of population that uses private toilet with a septic tank or flush/pour sewer system in their household. Shared toilet, SS indicates the same except the toilet is used by two or more households.

Si measures the unobserved or fixed effect, also called state heterogeneity. It represents all the factors that affect stunted or underweight children (below the age of 5 years) that do not change over time. For example, geographical features, differences in peoples' attitudes towards cleanliness[12].

The relationship between open defecation and child stunting has been examined in the literature. Availability of and access to improved toilet facilities can influence open defecation. There is however an implicit assumption in the literature that the existence of toilets leads automatically to elimination of open defecation. This may not always be so, as the decision can be affected by the quality of toilets, their maintenance, the availability of open spaces and other factors. This is captured by the following function.

Open Defecation=f (Private toilet, SS, Shared toilet, SS)

Thus, the availability of private and public/shared toilets is hypothesized to have both a direct effect on child stunting and underweight, and an indirect effect through open defecation. Taking account of State fixed effects, the above function can be written in the functional form as given in equation 2'.

$$OD_{\ it} = \alpha_0 + \alpha_1 * Pvt\ toilet_{it} + \alpha_2 * Shared\ toilet_{it} + \sum_{i=1}^{n=29} S_i + Eod_{it} \qquad (2')$$

OD is percentage of Open defecation and Eod is the error term.

Equations 1' & 2' are first differenced, over the 2 periods 2015-16 and 2019-21, to control for the unobserved state effects, to obtain equations 1 and 2:

$$\Delta Y_i = \ \varphi_1 * \Delta OD_i + \varphi_2 * \Delta pvt\ toilet_i + \varphi_3 * \Delta shared\ toilet_i + \vartheta \qquad (1)$$

$$\Delta OD_i = \alpha_1 * \Delta pvt\ toilet\ _i + \alpha_2 * \Delta shared\ toilet_i + \in_i \qquad (2)$$

Where $\vartheta\ is\ \Delta U_i$ and $\in_i = \ \Delta Eod_i$. Substituting equation 2 into equation 1 and rearranging, yields the reduced form equation 3':

$$\Delta Y_i = \varphi_1 * \Delta Eod_i + (\varphi_1\alpha_1 + \varphi_2) * \Delta pvt\ toilet_i + (\varphi_1\alpha_2 + \varphi_3) * \Delta shared\ toilet_i + \vartheta \qquad (3')$$

Or,

$$\Delta Y_i = \ \beta_1 * \Delta Eod_i \ + \beta_2 * \Delta pvt\ toilet_i + \beta_3 * \Delta shared\ toilet_i + \vartheta \qquad (3)$$

[12] Different states may have different attitudes towards cleanliness; they are typically slow to change. Many other factors may not exactly be constant, but they may roughly be constant over a five-year period.

Where $\beta_1 = \varphi_1$; $\beta_2 = (\varphi_1\alpha_1 + \varphi_2)$; $\beta_3 = (\varphi_1\alpha_2 + \varphi_3)$; $\in_i = \Delta Eod_i$

Even though equation 3 represents the central hypothesis of this paper, we can test for other hypothesis in the literature, within the format of this model. Poor quality of drinking water can lead to water borne diseases such as cholera, typhoid, jaundice and diarrhoea. Batool et al., (2023), have found that water quality increases stunting in children especially when the water source is coming from hand pumps and tanks.[13] As we do not have data on contaminated water, but only on unimproved and improved source of drinking water, we test for unimproved source of drinking water that comprises water from unprotected dug well, unprotected spring and surface water. The degree of contamination is not known.

According to UNICEF, early initiation of breastfeeding, exclusive for the first 6 months, followed by introduction of complementary foods post six months, along with continued breastfeeding up to the age of 2 years, provide nutrition, boost children's immunity and promotes brain development. If a child is not exclusively breastfed, (s)he is likely to be fed some liquid or semisolid food items. As water may be used to prepare semi-solid foods for toddlers, there is a possibility of unsafe water being ingested by the child. Exclusive breastfeeding rules out this possibility. However, it is difficult to separate this effect from the immunizing effect of breast feeding.

Equation 4 is used to test for the effect of water on stunting and underweight in children.

$$\Delta Y_i = \beta_1 * \Delta Eod_i + \beta_2 * \Delta pvt\ toilet_i + \beta_3 * \Delta shared\ toilet_i + \beta_4 * \Delta Z_i + E_{1i} \quad (4)$$

Where, Z is unimproved drinking water/ children exclusively breastfed (%) and E_{1i} is the error term.

Another factor considered important by the medical profession is nutrition. A child can acquire nutrition from breast milk, complementary foods, and foods rich in proteins & micronutrients such as vitamins and iron Children who are older than 6 months are provided semi-solid foods to complement the breast milk fed to them so that they develop and grow. This study uses iron-rich and vitamin A rich foods consumed by children in the last 24 hours to measure micronutrient intake among children (9-23 months). As lack of nutrition has been considered a cause of malnutrition in children (Gulati, 2010; Ijarotimi, 2013), this is tested by estimating equation 5.

$$\Delta Y_i = \beta_1 * \Delta Eod_i + \beta_2 * \Delta pvt\ toilet_i + \beta_3 * \Delta shared\ toilet_i + \beta_4 * \Delta Nutrition_i + E_{2i} \quad (5)$$

Here, Nutrition is Micronutrient intake measured by, iron-rich foods, Vitamin A-rich foods and complementary food intake. E_{2i} is the error term.

Another factor often emphasized by development economists is the prevalence of low income and poverty. In its review of multiple studies, Rahma and Mutalizimah (2022)'s research results showed that there was a relationship between family income and the incidence of stunting in children in the age group of 12 months to 59 months. However, Heltberg (2009) found the

[13] Virmani (2012), that improved sources of water to be significant in explain cross country variation in underweight indicator.

association between economic growth and chronic malnutrition to be very small (but statistically significant). Sahiledengle (2022) found that children from poor households had "higher odds of being stunted compared with children from the richest households". This study evaluates the effect of income (per capita GDP) on child stunting (height for age) and underweight (weight for age), by estimating equation 6.

$$\Delta Y_{it} = \beta_1 * \Delta Eod_i + \beta_2 * \Delta pvt\ toilet_i + \beta_3 * \Delta shared\ toilet_i + \beta_4 * \Delta Income_i + \omega \qquad (6)$$

Income is measured by Per Capita Net State Domestic Product and ω is error term.

Other variables found significant in determining child underweight, include Virmani (2007), which found the effect of DPT vaccines to be significant in explaining underweight children. It also found per capita expenditure on ICDS program in states (2005-06) to be significant. This paper, however, tests for the variable "utilization of ICDS services" to determine their role in explaining stunting and/or underweight in children. Female education and media exposure were also found to be significant in one of the models used by Virmani (2007). These variables are also tested within the framework of the model.

4.2 Child Mortality

Under five mortality or child mortality, a measure of number of deaths of children less than 5 years old per live births, has been found to be associated with sanitation and sewage systems. A very recent study, Chakrabarti et al. (2024), finds that the presence of toilets or an increased sanitation coverage through construction of private toilets, reduces child mortality.

The bold arrows in the model framework (figure 1), illustrated the possible relationship between sanitation and malnutrition. We hypothesize that sanitation works through stunting and/or underweight in children, to affect child mortality. As sanitation affects child malnutrition, this implies that the effect of toilets on mortality is indirect, working through its effect on stunting and/or underweight. The reasoning behind the hypothesis derives from the concept of Environmental Enteric Dysfunction (EED). EED caused due to constant fecal contamination, alters the functioning of the small intestine in children, reducing their ability to absorb nutrition from food. This may lead to greater prevalence of stunting and underweight in children and thus lead to child mortality. One way this could happen, is a disease which may not be life threatening to a normal child but increases the odds of mortality in malnourished children.

Recall that Female education was highly corelated with child mortality (-0.7 in table 3). Hence, we model it as follows,

Child mortality = f (female education, stunted/underweight children)

This function can be written as:

$$Child\ mortality = \theta_0 + \theta_1 Fedu_{it} + \theta_2 Malnutrition_{it} + \sum_{i=1}^{29} Si + T_{it} \qquad (7')$$

Writing the above equation in the first differenced form,

$$\Delta Child\ mortality_i = \theta_1 * \Delta Fedu_i + \theta_2 \Delta Malnutrition + \tau_i \qquad (7)$$

Where Fedu is females with more than 10 years of schooling (%), Malnutrition is stunted or underweight children (%) and $\tau_i is\ error\ term$.
To test for other factors like nutrition and government programs (immunization drive, ICDS) apart from female education and stunted/ underweight children that may explain child mortality, we add X to equation 7' and ΔX to equation 8 to get,

$$\Delta Child\ mortality_i = \theta_1 * \Delta Fedu_i + \theta_2 * \Delta Malnutrition_i + \theta_3 * \Delta X_i + \epsilon_{1i} \quad (8)$$

Where, X_i is Children aged 12-23 months who received all basic vaccinations/ no. of Anganwadi workers/ percentage of children with diarrhea/ and percentage of children who had vitamin A-rich or iron rich foods in the 24 hours preceding the NFHS survey. ϵ_{1i} is the error term

According to WHO, "Access to basic lifesaving interventions such as skilled delivery at birth, postnatal care, breastfeeding and adequate nutrition, vaccinations, and treatment for common childhood diseases can save many young lives" [14]. In this context, we test for nutrition measured by iron-rich and vitamin A rich foods, vaccinations and diarrhoea, a common childhood disease, as a determinants of child mortality. One of the aims of the ICDS program in India is to improve the health and development of children under the age of six. Anganwadi workers play a crucial role in the program by providing information on healthy food that should be a part of children's diet. Thus, we also test for Anganwadi workers in equation 8.

We use children vaccinated against DPT, media exposure and utilization of ICDS services as our X variable. Media exposure has been tested in the model as it is a source of disseminating information on maintaining good health (Virmani, 2007).

4.3 Diarrhoea

Diarrhea is the third leading cause of mortality for children under age 5 worldwide and is a leading cause of malnutrition in children in that category (WHO). Although diarrheal disease is described as a water borne disease, it may in fact be an "excreta-related disease" because the pathogens affecting the stomach are derived from fecal matter (Kumar and Vollmer, 2012). The breaking of the infection cycle depends primarily on hygiene and sanitation i.e. hand washing and toilet use. Contaminated water may also lead to infection which may lead to diarrhea in children. Therefore, we test for the effect of sanitation and water quality on children with diarrhea (non-chronic)[15]. We define the function for Diarrhea as,

Diarrhea = f (Sanitation, Drinking water quality)

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[14] https://www.who.int/news-room/fact-sheets/detail/children-reducing-mortality#:~:text=Access%20to%20basic%20lifesaving%20interventions,premature%20mortality%20in%20older%20children.

[15] Diarrhea may itself cause slow growth or persistent weight loss when it is chronic in nature (Gorospe and Oxentenko, 2012). Since we do not have data on chronic or severe diarrhea, we thus test for the effect of non-chronic, non-severe diarrhea in this paper, only to find it to be an insignificant determinant of malnutrition

Sanitation is measured by private and shared toilets with a sanitation and sewage system. The model of the function translates into the functional form 9' and after first differencing, into the estimating equation 9.

$$Diarrhea_{it} = \gamma_0 + \gamma_1 * Sanitation_{it} + \gamma_2 * Water\ quality_{it} + \sum_{i=1}^{n=29} Si + E_{1it} \qquad (9')$$

$$\Delta Diarrhea_i = \gamma_1 * \Delta Sanitation_i + \gamma_2 * \Delta Water\ quality_i + \varepsilon_{1i} \qquad (9)$$

Water quality is measured by improved source of drinking water /unimproved source of drinking water (%), Sanitation is measured by Private toilet, SS and Shared toilet, SS. ε_{1i} is the error term

5.Results and Discussion

5.1 Malnutrition Estimates

Table 4 summarizes the estimation results of equations (1), (2) and (3). The estimates of open defecation in equation 2, shows that private toilet, SS is a highly significant determinant of open defecation. A one percent increase in the use of private toilets, leads to a 0.84% decrease in open defecation. Shared toilet, SS, however, is not a significant determinant of open defecation.

A comparison of the results of equation 1 and equation 3 (for stunting and underweight) is interesting. The effect of an increase in percentage of population using shared toilets is highly significant and virtually identical in the two equations. The effect of shared toilets on stunting is -0.92% and -0.94% and on underweight the effect is -1.05% and -1.06% for equations 1 and 3 respectively. These effects are significant at the 1% level. As the use of shared toilets is insignificant in explaining prevalence of open defecation (equation 2), its direct impact on stunting or underweight in equation 1, is the same as the direct impact of shared toilet coefficients in equation 3, with same level of significance[16].

The effect of "open defecation" is also identical in both impact and significance in the two equations. The effect of one percent increase in open defecation on underweight children, at 0.18%, is slightly larger than its impact on stunting at 0.15%. The former is also more significant (at the 1% level) than the latter (at the 5% level).

The effect of private toilets, SS on stunting and underweight is however quite different in the two equations. It is significant in equation 3, but insignificant in equation 1, because we have taken account of the effect of private toilets on OD (equation 2), in equation 3. The effect and significance of private toilets is higher for underweight than for stunting (equation 3). A one percent increase in use of private toilet with sewage system leads to a 0.15 percent point decrease in underweight children and a 0.093 percent decline in stunted children. The former is significant at the 1% significance level and the latter at 5% significance level (table 4).

[16] From the estimates of equation 2, we find α_2 to be insignificant, i.e., statistically it is not different from zero. Since $\alpha_2 = 0$, substituting this into equation 3a, we get $\beta_3 = (\varphi_1 * 0 + \varphi_3) = \varphi_3$. Hence the impact of use of shared toilets on stunting and underweight is same for both equations 1 and 3.

Overall, the adjusted R squared value of 0.55 suggests that the model in equation 3 explains 55% of the difference in percentage of underweight children across Indian States. The adjusted R squared for stunting is lower at 0.39, suggesting that explanatory value of equation 3 for stunting is only 39%. One reason for this is that stunting is likely to be a slower process than underweight and may not be as prominent during a 4-to-5-year period.

Table 4: Child malnutrition & Toilets with sanitation and sewage systems

	Equation 1		**Equation 3**			**Equation 2**
Independent variables	**Stunted**	**Under weight**	**Stunted**	**Under weight**	**Wasted**	**Open defecation**
(S.E. in brackets)						
Private toilet, SS	0.037	0.0056	-0.093**	-0.15***	-0.10**	-0.84***
	(0.062)	(0.061)	(0.035)	(0.035)	(0.04)	(0.11)
Shared toilet, SS	-0.92***	-1.05***	-0.94***	-1.06***	-1.14***	-0.09
	(0.29)	(0.28)	(0.29)	(0.28)	(0.39)	(0.92)
Open Defecation (OD)	0.15**	0.18***				
	(0.06)	(0.06)				
Eod= Actual OD-Predicted OD			0.15**	0.18***	0.09	
			(0.06)	(0.06)	(0.08)	
R squared	0.45	0.6	0.45	0.6	0.33	0.68
Adjusted R squared	0.39	0.55	0.39	0.55	0.25	0.65
No. of observations	29	29	29	29	29	29
Note: * =p < 0.10; ** = p < 0.05; ***= p <0.01						
Data Source: NFHS 4 and 5; Note: All regressions are in first difference						

As private toilets are found to be highly significant in estimates of equation 2, this result corroborates our model in which open defecation depends on availability and use of sanitation facilities. As per our knowledge, other studies have neither hypothesized nor econometrically estimated this relationship.

Although open defecation has been found to affect child stunting in many studies, our results highlight the importance of the different qualities of sanitation-private toilet and shared toilet with a sanitation and sewage system- in addition to open defecation, not only in determining stunted children, but also underweight children. Shared toilet, SS that exhibited low correlation with stunted and underweight children as shown in table 3, is opposite to our results that in fact show a more than proportionate decrease in the percentage of underweight children with an increase in use of shared toilets. The change for stunted children is also very high.

Wasting (weight-for-height), unlike underweight (weight-for age) and stunting (height-for-age), is a ratio of two variables both of which are affected by sanitation. We therefore expect this variable to have little effect on Wasting. The estimation results of equation 3, with Y_i as the percentage of wasted children below 5 years, show that Open defecation (Eod) is insignificant. This contrasts with results for stunting and underweight and implies that Open defecation does not explain inter-state differences in Wasting. However, private toilet, SS and Shared toilet, SS are significant at 5% and 1% level respectively (columns headed equation 3 in table 4). The adjusted R squared of 0.25 (column 5) suggests that 25% of the inter State variation in wasted children is explained by the independent variables- private toilet, shared toilet.

Our estimates for the effect of Open defecation on wasting is contradictory to the result of Sahiledengle et al. (2022). While Sahiledengle et al. (2022) find open defecation to be a significant determinant of wasting in children, they neglect the effect of private toilets on open defecation. The importance of this shortcoming is illustrated by the following regression, which also does not take account of the effect of private toilets on OD. Consequently, it wrongly finds OD to be a significant determinant of child wasting.

$$\Delta Wasted\ children_i = 0.10 * OD_i - 1.12 * shared\ toilet_i$$

(0.04)** (0.38)*** $\bar{R}^2$=0.28

Our results are, however, consistent those of van Cooten et al. (2018), Aheto et al. (2015) and Das et al. (2022)[17].

Table 5 presents the results of unimproved source of drinking water on stunting, underweight and wasting, derived from equation 4. Unimproved water is found to be insignificant, but the sanitation variables, private toilet, SS and Shared toilet, SS, remain significant. Private toilet, SS, is significant at 10% level in case of stunted children (column 1). Compared to equation 3 (table 4), the significance level of private toilet has gone down and so has the value of the coefficient. Open defecation (Eod) is significant at 5% level. Shared toilet, SS, is significant at 1% level with high coefficient values. A one percent increase in Shared toilet, SS decreases stunted children by 0.95% when testing for unimproved water.

For the case of underweight children, private toilet, shared toilet and Open defecation (Eod), all remain significant. The significance level of shared toilet is 1% and the coefficient value is -1.05. This is no different than the coefficient of shared toilet (-1.06) in equation 3, table 4. Open defecation (Eod) is significant at 5% level with the coefficient being 0.18.

[17] Van Cooten et al. (2018) include no toilet facility (i.e. open defecation) in the category of unimproved toilet facility, in determining the odds of wasting.

Table 5: Effect of drinking water on child malnutrition

Equation 4	(1)	(2)	(3)
Independent variables	**Stunted**	**Under weight**	**Wasted**
(S.E. in brackets)			
SS- private toilet	-0.083*	-0.16***	-0.12*
	(0.047)	(0.046)	(0.06)
SS-shared toilet	-0.95***	-1.05***	-1.12***
	(0.3)	(0.29)	(0.4)
Eod= Actual OD- Predicted OD	0.15**	0.18***	0.08
	(0.062)	(0.061)	(0.08)
Unimproved water	0.025	-0.035	-0.06
	(0.081)	(0.08)	(0.1)
R squared	0.45	0.6	0.34
Adjusted R squared	0.37	0.54	0.23
No. of observations	29	29	29

When wasted children are the dependent variable, we find private toilet and shared toilet to be significant. Open defecation (Eod) and drinking water play no role in determining the inter-state differences in wasted children. Exclusive breastfeeding is also found to be an insignificant determinant of stunting and Underweight.

Table 6 presents the estimation results of the effect of nutrition on malnutrition, estimated using equation 5. Measures of nutrition, namely Vitamin A rich foods, Iron-rich foods and complementary food intake (for children aged 6-23 months), are all found to be insignificant. This implies that nutrition has an insignificant role in explaining inter-state differences in child stunting, underweight and wasting.[18].

The estimates of private toilet, shared toilet and Open defecation (Eod) continue to remain significant for both stunted and underweight children. For the case of stunted children, private toilet and Open defecation (Eod) are significant at 5% (column 1) or 1% (column 4). Shared toilet is significant at 1% (column 1 & 4). In the case of underweight children however, the significance level of all sanitation variables remains 1% (column 2 & 5), same as the estimates of equation 3 (table 4). For the case of wasted children (column 3 & 6), the significance level of private toilet and shared toilet has gone down to 10% and 5% respectively compared to the result in table 4.

[18] Coefficients are within 1 standard deviation of mean of each other.

Table 6: Effect of Nutrition on Child Malnutrition

Equation 5	(1)	(2)	(3)	(4)	(5)	(6)
Independent variables (1st diff)	**Stunted**	**Under weight**	**Wasted**	**Stunted**	**Under weight**	**Wasted**
(S.E. in brackets)						
Private toilet, SS	-0.10**	-0.15***	-0.11*	-0.10***	-0.15***	-0.09*
	(0.04)	(0.04)	(0.05)	(0.034)	(0.038)	(0.05)
Shared toilet, SS	-0.96***	-1.06***	-0.1**	-0.88***	-1.08***	-1.15**
	(0.32)	(0.33)	(0.43)	(0.27)	(0.308)	(0.41)
Eod= Actual OD-Predicted OD	0.16**	0.19***	0.108	0.16***	0.19***	0.085
	(0.06)	(0.06)	(0.08)	(0.056)	(0.063)	(0.086)
Vitamin A rich foods	0.01	0.002	-0.17			
	(0.10)	(0.11)	(0.14)			
Iron rich foods	0.03	-0.007	0.13			
	(0.11)	(0.12)	(0.16)			
Complementary food intake				0.015	0.018	-0.017
				(0.031)	(0.035)	(0.04)
R squared	0.49	0.60	0.37	0.52	0.60	0.34
Adjusted R squared	0.38	0.51	0.24	0.43	0.54	0.22
No. of observations	28	28	28	27	27	27
Note: * =p < 0.10; ** = p < 0.05; ***= p <0.01.						
Data Source: NFHS 4 and 5; Note: All regressions are in first difference						

The estimates of equation 6, where we test for the effect of income on stunted and underweight children (independent variables) respectively are given as follows:

$$\Delta Y_i = 0.15 * \Delta Eod_i - 0.11 * \Delta pvt\ toilet_i - 0.88 * \Delta shared\ toilet_i + 0.000032 * \Delta Income_i$$

(0.06)** (0.044)** (0.30)*** (0.000034) $\bar{R}^2$=0.38

$$\Delta Y_i = 0.19 * \Delta Eod_i - 0.17 * \Delta pvt\ toilet_i - 1.01 * \Delta shared\ toilet_i + 0.000032 * \Delta Income_i$$

(0.06)*** (0.043)*** (0.29)*** (0.000034) $\bar{R}^2$=0.55

From the above equations, we conclude that income is an insignificant determinant of child stunting and underweight. Sanitation variables remain significant. We note that the significance level of private toilet and Open defecation (Eod) (5%) is lower in stunting equation than in underweight equation (1%). Note that numbers in parentheses are standard errors.

The effect of DPT vaccination, media exposure, female education, and stabilization of ICDS services on child stunting and underweight was found to be insignificant.

Following our main results derived from equations (2) and (3), the testing of the impact of water, nutrition and income on child stunting and underweight showed that these variables didn't explain the inter-state differences in stunted and underweight children. We also find water and nutrition to have no effect on child wasting. Our results support the findings of Headey et al. (2014) and Rah et al. (2020) that find no effect of piped water on growth outcomes. Our results also find no significant effect of water on underweight and wasted children. This is consistent with the findings of Das et al. (2022).

Nutrition, including breastfeeding for children in the age group of 0-23 months, is found to be insignificant in explaining inter-state variations in malnutrition. This result indicates that providing children with nutritious food may not help mitigate the problem of stunting, underweight and wasting if children are succumbed to gastrointestinal diseases that reduce their ability to absorb nutrition from food.

Our results also suggest that income does not play a role in explaining the variation in child stunting and underweight across states. While Heltberg (2009) found a very small association between economic growth and chronic malnutrition, our estimates didn't support the same when the effect of income was tested on malnutrition (not chronic malnutrition).

Weaver et al. (2024) finds that large increases in nutritional intake leads to improvement in child anthropometric indicators but only in areas with low rates of open defecation. We test for this possibility by dividing our micronutrient variables (intake of Vitamin A & Iron rich foods) according to the low and high OD states. The micronutrient variables are found to be insignificant in both low and high OD States (table A.2). This result implies that nutrition does not explain inter-State differences in child stunting and underweight even in States with low OD.

The estimation results of equations 3 to 6, thus confirm the existence of strong links between sanitation and malnutrition, open defecation and malnutrition and weak links between water, nutrition, income, and malnutrition. These links are illustrated in our model framework (figure 1) as solid and dashed arrows respectively.

5.2 Child Mortality estimates

The estimates derived using equation 7 are given in table 7. As mentioned in the methodology section, (section 4.2), 2 versions of equation 7 are used to determine the effect of malnutrition on child mortality. Female education remains significant at 1% level of significance for both the versions, reaffirming the importance of education in reducing child mortality. A 1% increase in female education reduces child mortality by more than 1%.

When stunted is taken along with female education, stunted is found to be significant at 5% level of significance (column 1). A one percent increase in stunted children reduces child mortality by 0.65 percent. When underweight is substituted for stunted (column 2), it is also found to be significant in determining child mortality at state level. A one percent increase in underweight children reduces child mortality by 0.52%. The effect of stunting on child mortality is thus higher compared to underweight.[19]

[19] When % of Wasted children is used instead of Stunted or underweight children (%), in the equation for child mortality, it is not significant.

Table 7: Effect of Child Malnutrition on Child Mortality

Equation 7				
Independent variables	**Under five mortality**			
(S.E. in brackets)	(1)	(2)	(3)	(4)
Female education (>10 years)	-1.07***	-1.08***	-1.06***	-1.3***
	(0.16)	(0.17)	(0.31)	(0.30)
Stunted children	0.65**		0.88**	
	(0.26)		(0.32)	
Underweight children		0.52**		0.84***
		(0.23)		(0.30)
Private toilet, SS			0.05	0.17
			(0.107)	(0.11)
Shared toilet, SS			0.72	0.59
			(0.70)	(0.66)
R squared	0.68	0.67	0.61	0.71
Adjusted R squared	0.66	0.65	0.58	0.66
No. of observations	29	29	29	29
Note: * =p < 0.10; ** = p < 0.05; ***= p <0.01.				
Data Source: NFHS 4 and 5, Economics Survey 2023-24 Statistical Appendix;				
Note: all regressions are in first difference				

The adjusted R square value of 0.66 and 0.65 suggests that 66 or 65 percent of the variation in the independent variables explain the variation in child mortality rates. Since the version with stunted alone gives us a higher adjusted R-squared and higher coefficient value of the malnutrition variable, this version is considered our main child mortality equation.

Recent district level study conducted on the effect of toilet construction under the Swachh Bharat Mission (SBM) on child mortality (Chakrabarti et al., 2024) finds reduction in child mortality in the SBM period compared to the pre-SBM period. These results, however, are held in the background of improvements in maternal education, antenatal care, hospital births, health insurance and higher utilization of health and nutrition programs.

If we test for the effect of sanitation variables Private toilet, SS and Shared toilet, SS in our child mortality equations (columns 3 & 4), these variables are found to be insignificant whereas female education and malnutrition variables remain significant[20]. These results imply that private and shared toilets affect child mortality indirectly, through their effect on stunting and underweight children.

[20] Even if stunted/ underweight is removed from the child mortality equation, private and shared toilet remain insignificant in explaining inter-state differences I child mortality.

The results of equation 8, where we test the effect of nutrition (measured by vitamin A and iron rich foods), vaccinations and ICDS program (number of Anganwadi workers) are shown in Table 8.

The estimates show that all these variables are insignificant in explaining the inter-state differences in child mortality, while female education and stunted children remain significant, as in table 8. The coefficients for the effect of percent of stunted children vary between 0.5 to 0.7, depending on which additional variable (represented by K in equation 8) is being tested for. The estimation results for underweight children, as an explanatory variable, are given in table A.3 of the appendix.

Table 8: Effect of Child Nutrition & Vaccination on Child Mortality

Equation 8					
Independent variables	**Child mortality (under 5 years)**				
(S.E. in brackets)					
Female education (>10 years)	-1.16***	-1.20***	-1.12***	-1.12***	-1.09***
	(0.18)	(0.18)	(0.25)	(0.17)	(0.18)
Stunted children	0.57**	0.51**	0.50*	0.66**	0.68**
		(0.28)	(0.28)	(0.26)	(0.28)
Vitamin A rich foods	0.16				
	(0.12)				
Iron rich foods		0.046			
		(0.13)			
Basic vaccination			-0.045		
			(.10)		
No. of Anganwadi workers				0.00016	
				(0.00014)	
Diarrhoea					-1.09
					(0.37)
R squared	0.73	0.71	0.71	0.70	0.68
Adjusted R squared	0.70	0.68	0.68	0.66	0.65
No. of observations	27	27	28	29	29
Note: * =p < 0.10; ** = p < 0.05; ***= p <0.01. Note: All regressions are in first difference					
Data Source: NFHS 4 and 5, Economic Survey 2023-24 Statistical Appendix					

5.3 Diarrhoea estimates

The estimation results of equation 9 are presented in the following equation. Private toilet is found to have a significant effect on children with diarrhea, at 1% level of significance. A one percent increase in use of private toilets with sanitation and sewage system leads to a 0.11 percent decrease in the percentage of children who had diarrhea two weeks before they were surveyed. Shared toilet with sanitation and sewage system and unimproved drinking water were found to be insignificant.

$$\Delta Diarrhoea = -0.11 * \Delta pvt\ toilet_i + 0.08 * \Delta shared\ toilet_i - 0.062 * \Delta Unimproved\ water_i$$
$$(0.043)^{***} \quad (0.27) \quad (0.074) \quad \bar{R}^2 = 0.16$$

The use of private toilet, SS is highly significant in explaining the prevalence of diarrhea in children. Diarrhea can be caused by consumption of contaminated food and water, or the germs can also be spread through the contamination of surface by dialarhoea causing germs. Having access to a private toilet may prevent the spread of germs, with toilet facilities being maintained regularly, having wash basins and working taps in these toilets. Use of all these amenities help break the infection cycle. Water quality is however, not found to be significant, and therefore not relevant for explaining the inter-state differences in percent of children affected by diarrhoea. This supports the argument by Kumar and Volmer (2012) that diarrhea is not a water borne-disease but an excreta-related disease.

6. Simulation of effects of improved toilet facilities

In this section we use the estimated coefficients of child stunting, underweight and child mortality to estimate the simulated effect of further improvement (since NFHS 5 survey) in quality of sanitation facilities (i.e., more of Private toilet, SS and Shared toilet, SS) on child malnutrition and child mortality. In addition, we use the estimated coefficients of female education to estimate the simulated effect of further improvement in female education on child mortality, given the government's ongoing program of "Beti Bachao, Beti Padhao".

We use the State-wise population projections by age, made in the Report of the Technical Group on Population Projections (November 2019) for this purpose. Data is available for only 20 states and Jammu & Kashmir, compared to the 29 states & UTs in NFHS survey.[21] As the projection for children 4-5 years old is not available, we use the average number of children in the 0-4 years age group for each State as an estimate of children 4–5 years old, to obtain an estimate of the 0–5 years old in each State.

The simulation for estimating the impact on child malnutrition assumes that availability and use of Private toilet, SS and Shared toilet, SS is increased in every State, by a per cent equal to the use of "other' sanitation facilities[22] in each state, with half of the "other" replaced by private toilet, SS and the other half by shared toilet, SS. We then use the parameter estimates from our model to estimate the changes in stunting and underweight.

For instance, in table 9, column 2, 19.2% of the population of Uttar Pradesh uses other sanitation facilities. If this value is reduced completely to zero and half of it is moved to Shared toilet, SS and half to Private toilet, SS, then private toilet, SS and Shared toilet, SS, each increase by 9.6 percentage points.

[21] Separate population projections are not available for Sikkim, Arunachal Pradesh, Manipur, Mizoram, Nagaland, Meghalaya, Tripura and Goa.
22 Others include unimproved sanitation facilities, and all facilities not included in Private toilet, SS, Shared toilet, SS.

Table 9: Simulated changes in Private and Shared toilets with sewage systems

States	Total (21)	UP	Assam	WB	Bihar	Jharkhand
Private toilet, SS	58.18	52.2	33.2	53.6	43.8	30.1
Change in Private	7.15	9.6	28.8	11.7	4.7	16.8
Shared toilet, SS	6.45	6.4	5.2	11.1	8.8	3.4
Change in Shared	7.15	9.6	28.8	11.7	4.7	16.8
Others	14.31	19.2	57.5	23.4	9.3	33.6
Change in others	-14.31	-19.2	-57.5	-23.4	-9.3	-33.6

The totals in column 1 of table 9 are weighted averages of the 21 States & UTs, calculated using the share of children (0-5) in each state as weights. The total column therefore shows that the simulation leads to an overall reduction of 14.3% points in "other" sanitation and an average increase of 7.15% points each in the use of SS-private and Shared toilet, SS (column 1, table 9)

The changes in percent point of stunted, underweight and wasted children are calculated using the following equations:

$\Delta Stunting_i = -0.093 * \Delta pvt\ toilet_i - 0.94 * \Delta shared\ toilet_i$, i = 1,….,21

$\Delta UnderWeight_i = -0.15 * \Delta pvt\ toilet_i - 1.06 * \Delta shared\ toilet_i$, i = 1,….,21

$\Delta Wasted\ children_i = -0.10 * \Delta pvt\ toilet_i - 1.14 * \Delta shared\ toilet_i$, i= 1,….,21

The results are shown in Table 10. As mentioned before, the Total column shows the weighted average of the effect on 21 States & UTs. The number of affected children is calculated by applying the % change in each state to the number of children (0-5) in that State.

The aggregated effects can be summarized as follows. An average increase of 7.15 percentage point in each of Private and Shared toilets with a Sanitation and sewage system, leads to -7.38 percentage point decrease in stunted children, -8.58 percentage point decrease in underweight children and -8.87 percentage point of wasted children[23]. This is estimated to reduce the number of stunted children by an average of 10 lacs, the number of underweight children by an average of 11.6 lacs and the number of wasted children by an average of 12 lacs. The states of Uttar Pradesh, Assam, West Bengal, Bihar and Jharkhand are the top 5 states to experience large improvements in the number of stunted, underweight and wasted children. (table 10).

[23] The effect of the simulated improvement in Private toilets with sanitation and sewage is a reduction of 6 percentage points in open defecation.

Table 10: Simulated effect of Improved Sanitation on Child Malnutrition

Simulation: Effect of Private & Shared toilets on Child malnutrition & Mortality						
States	**Total (21)**	**UP**	**Assam**	**WB**	**Bihar**	**Jharkhand**
Stunted 2019-21	35.92	39.7	35.3	33.8	42.9	39.6
Change in Stunting (%)	-7.38	-9.9	-29.7	-12.1	-4.8	-17.3
Elasticity w.r.t. SS	-0.52					
Change in Stunting (nos)	-1,001,221	-294,046	-112,153	-95,931	-80,944	-79,341
Underweight 2019-21	32.61	32.1	32.8	32.2	41.0	39.4
Change in under-wt (%)	-8.58	-11.5	-34.5	-14.0	-5.6	-20.2
Elasticity w.r.t. SS	-0.60					
Change in underwt (nos)	-1,164,211	-341,914	-130,410	-111,548	-94,121	-92,257
Wasted 2019-21	19.49	17.3	21.7	20.3	22.9	22.4
Change in wasting (%)	-8.87	-11.904	-35.65	-14.508	-5.766	-20.832
Change in wasting (no.s)	-1204499	-353311	-134757	-115266	-97258	-95332
Open defecation	21.1	22.2	4.1	11.9	38.1	32.9
Change in OD	-6.01	-8.1	-24.2	-9.8	-3.9	-14.1

There are several other simulations possible. For instance, we can replace the "other" sanitation facilities, by Private toilet, SS and Shared toilet, SS in proportion to the existing shares of these two types in each state. In this simulation the reduction in the numbers of stunted children is 3.6 lakhs, in underweight is 4.8 lacs and in wasted is 4.1 lacs.

The simulation for estimating the impact of improvement in sanitation facility on mortality requires estimating the percentage point change in stunted children as estimated above. The simulation for estimating the impact of improvement in female education on child mortality assumes that female schooling is increased in every state by the same percentage points as the increase in female schooling between 2015-16 and 2019-21. We then use the parameter estimates from our model to estimate the changes in mortality.

The changes in percent point of child mortality are calculated using the following equations:

$$\Delta Child\ mortality_i = 0.65 * \Delta Stunting_i - 1.07 * \Delta Fedu_i \text{ , i = 1....21}$$

The results are shown in table 11. The Total column shows the weighted average of the effect on 21 States & UTs, as in table 10. The number of affected children is calculated by applying the % change in each state to the number of children (0-5) in that State.

At the aggregate level an average increase of 7.2 percentage point in each of Private and Shared toilets with a sanitation and sewage system, leads to -7.4 percentage point decrease in stunted children. This change in stunted children is used to calculate the change in child mortality. As a result, we find that child mortality decreases by -4.8 percentage points. This is estimated to reduce child deaths by 6.5 lacs. Uttar Pradesh, Assam, West Bengal, Bihar and Jharkhand see the largest improvement in child mortality as a result of the decrease in stunting (table 11).

Table 11: Improved female education & child malnutrition & mortality

Simulated Effect of reduced malntrition & Female Education on Child mortality						
	Total (21)	**UP**	**Assam**	**WB**	**Bihar**	**Jharkhand**
Child mortality 2019-21	21.06	59.8	39.1	25.4	56.4	45.4
Change in mortality (s)(%)	-4.80	-6.4	-19.3	-7.8	-3.1	-11.3
Elasticity w.r.t. SS	-0.34					
Change in mortality (s) (nos)	-650,794	-191,130	-72,899	-62,355	-52,613	-51,572
Female education	38.88	39.3			28.8	
Change in female education	5.9	6.4			6.0	
Change in mortality (f) (%)	-6.31	-6.8			-6.4	
Change in mortality (f) (nos)	-857173	-203249			-108289	
Elasticity w.r.t. Fedu	-1.07					
Note: s and f in brackets indicate changes in child mortality due to change in sanitation (and thus stunting) and female education resp.						

The reduction in child fatalities resulting from replacing the "other" sanitation facilities, by Private toilet, SS and Shared toilet, SS in proportion to the existing shares of these two types in each state would be 2 lacs.

The potential impact of an increase in female education is also simulated using the estimated equation. We calculate the increase in per cent of females who have passed class 10 in each state between the two surveys and simulate the effect of replicating this from the 2019-21 level. The weighted average is an increase of 5.9 percentage point in female schooling (more than10 years). This reduces child mortality by -6.3% points or 8.5 lac children. The states of Uttar Pradesh, Bihar, Maharashtra, Rajasthan and Madhya Pradesh are the top 5 states to experience large reductions in the number of child fatalities due to improvement in female education (table 12). Another simulation calculates the gap between the 2019-21 level and 100% in each State and simulates the effect of closing 1/10th of this gap in each State. This would decrease the number of child deaths by 8.8 lacs.

7. Government Initiatives

7.1 Swachh Bharat Mission

The Swachh Bharat Mission-Gramin (SBM-G) was launched by the government of India on 2nd October 2014 to boost the sanitation coverage, improve cleanliness and eliminate open defecation in India by 2nd October 2019[24]. Considered to be the country's biggest drive to improve sanitation, hygiene and cleanliness in the country, construction of Individual Household Latrines (IHHL) was one of the main activities among others such as construction of Community Sanitary Complexes, Solid Liquid Waste Management activities, and Information, Education and Communication activities. Under phase 1 of the SBM-G, a subsidy of INR 12000 was provided for the construction of IHHL on demand, out of which 60% contribution (Rs.7200) was made by the Centre and 40% (Rs. 4800) was made by the state.

[24] https://swachhbharatmission.ddws.gov.in/

The corresponding figures for Northeast states, J&K and special category states were 90% (Rs.10800) and 10% (Rs. 1200).

To assess the progress of sanitation in rural India, the Ministry of Drinking Water and Sanitation (with World Bank support) conducted the National Annual Rural Sanitation Survey (NARSS) across rural India from 2017-18 to 2019-20. The survey showed that "as the SBM (G) started, it led to a substantial increase in access to own or shared improved toilets in rural India - from 38% in 2012 to 90% in 2019-20 - with the sharpest increase reported in the last two years of this time period" (The Hindu, 2023).

Swachh Survekshan Grameen 2022, interviewed 1,75,221 households in 17,559 villages, It found that 95.4% of surveyed households had access to toilet and 95.4% of those having toilet have been using it regularly (PIB Delhi, 2023)[25]. This implies over 90% usage of toilets.

According to the UNICEF, post the implementation of Swachh Bharat Mission, 100 million rural households and 500 million residents gained access to toilets across 630,000 villages. Households in open defecation free toilets saved up to Rs. 50,000 on average annually due to avoidance of health costs. Additionally, UNICEF (2019) found SBM to have a positive impact on the environment, with 12.70 times less likelihood of groundwater contamination and 2.4 times less likelihood of piped water contamination traceable to humans in Open defecation free (ODF) villages[26].

Chakrabarti et al. (2024) in its introduction said that "SBM's approach of combining toilet construction with substantial construction with substantial investments in IEC and community engagements differ markedly from prior sanitation efforts in India. However, despite the increase in household toilet availability and government reports of considerable reduction in open defecation post implementation of SBM, concerns regarding actual utilization of toilets, sustained behaviour change and overreporting of Open Defecation Free (ODF) status of Indian regions remain." It then went on to estimate its own model and estimates. It used a two-way fixed effects regression model to estimate the association between toilets constructed under the Swachh Bharat Mission (SBM) and child mortality. The panel data regression results showed that districts with greater than 30% toilets constructed under SBM corresponds with 5.3 lower infant mortality rates and 6.8 lower child mortality rates (under 5), They assert that the post-SBM period in India showed "accelerated reductions in infant and child mortality compared to pre-SBM period". They further state that based on their estimates, provision of toilets at-scale may have contributed to preventing roughly 60,000-70,000 deaths annually.

7.2 Beti Bachao, Beti Padhao

The Government of India introduced the scheme named Beti Bachao, Beti Padhao (BBBP) in the year 2015 to address the concerns regarding gender discrimination and women empowerment in the country. The scheme aims to educate citizens against gender bias and

[25] Press Release: Press Information Bureau (pib.gov.in)

[26] Report on the environmental impact of the Swachh Bharat Mission (SBM) on water, soil and food | UNICEF India

improve the efficacy of welfare services for girls[27]. There are multiple monitorable targets related to health, education and attitudinal change under this scheme. The education related monitorable targets are: One, increase enrolment of girls in secondary education to 82% by 2018-19, two, provide functional toilet for girls in every school in selected districts and three, train Elected Representatives/ Grassroot functionaries as Community Champions to mobilize communities to improve CSR and promote Girl's education (PIB, 2022)[28].

An evaluation of monitorable targets in the Beti Bachao, Beti Padhao scheme, showed that betwee(Anti-15 and 2019-20, (1) Sex ratio at birth increased from 918 to 934, (2) Enrolment of girls in secondary education increased from77.4% to 81.3%, (3) first trimester ANC (Antenatal Care) registration increased from 61% to 71% and (4) Institutional deliveries increased from 87% to 94% (Agarwal, Rathi & Sabharwal, 2023). In addition to this, the percentage of schools with functional separate toilets for girls showed improvement from 92.1% in 2014-15 to 95.1% in 2018-19 (provisional), as per UDISE-data (PIB, 2023).

8. Conclusion and Policy Implications

This paper presented a comprehensive model of public health measures on child malnutrition and mortality. Public health measures (*Quasi Public goods*) include sanitation and sewage, clean drinking water and public health education. The model was estimated using two period panel data of Indian States. The estimates authenticated and confirmed the key new elements of the model.

The results support the decades long assertion of one of the authors, that India's high child malnutrition levels are due more to malabsorption of nutrition in the guts, than to availability or lack of nutritious food.[29]. In medical terms, *Environmental Enteropathy*, now called *Environmental Enteric Dysfunction (EED)* has been subsequently proved to be a major cause of under-five child malnutrition (stunting, underweight, wasting)

There are now a number of socio-economic studies which investigate the odds of malnutrition in the absence of improved sanitation or lack of toilets, and few which investigate the effect (odds) of different types of toilet facilities defined in terms of their sewage-sanitation systems (SS). This is perhaps the first study to investigate the different impact of private and shared toilets, and the effect of improved sanitation along with open defecation, on child malnutrition (stunting and underweight).

This paper showed that the availability and use of private and shared toilets with improved sewage systems have significant but different effects on stunting and under-weight. In the Indian socio-economic context, these two sanitation variables explain a greater proportion of inter-state variation in child under-weight than stunting. This is probably because stunting is a longer-term phenomenon than becoming underweight. The effect of open defecation on stunting and underweight remains significant but is overshadowed by the effect of the

[27] Beti Bachao Beti Padhao
[28] PIB (2022) doc202261364301.pdf
[29] Virmani (2007b)

sanitation variables. The key indirect effect is of private toilets on open defecation, which other studies have not accounted for; This could have resulted in the over-estimation of the role of open defecation relative to sanitation.

The most noteworthy feature of the paper is the significant effect of Child malnutrition on Child mortality. The implication of this result is that both Stunted and Under-weight children are more vulnerable to mortality triggered by other causes such as life-threatening diseases. In other words, the probability of death due to these diseases is higher for stunted and under-weight children than for normal children (under 5). Improved sanitation- private and shared, therefore reduces child malnutrition, which in turn reduces child mortality across Indian States.

Access to and use of public health information, proxied in our study by female education levels, is also found to have a significant effect on child mortality. There are many sources of public health education, like media, internet & web platforms, government programs, educational programs, pamphlets & books. Availability does not lead automatically to understanding unless one has the education to understand it. Mothers are best positioned to translate their knowledge into action. Mother's education is critical for understanding and using information about child health & well-being. We therefore find a strong and significant effect of female education on child mortality. Simulations show that another 5.9 per cent points improvement in the per cent of females with more than 10 years of education, would reduce child mortality 6.3% points. This reinforces many earlier studies on the important role of female education, on the economy and society.

We find that. drinking water quality, mild diarrhea, per capita income and measured nutrition (iron-rich and vitamin A rich foods,) are statistically insignificant in explaining inter-State differences in child stunting, under-weight and mortality.

The most important policy implication relates to the Swachh Bharat mission (SBM). The large increase in private and public toilets has had a significant effect in reducing the prevalence of underweight and stunted children and in reducing child mortality. Simulations suggest that a replacement of the remaining lower quality toilets by toilets connected to sewage systems or other high quality disposal systems can reduce percent of Stunted children by 7.8%, under-weight by 8.6% and child mortality by 4.8%.

With toilets continuing to be constructed under Swachh Bharat program during FY21 to FY24, universal access to toilets will be attained soon. Attention of public health policy should shift to ***improving the sewage collection, treatment systems in urban, semi-urban and semi-rural areas of each State***.[30] History shows that installation of modern sewage systems in large cities like London and New York transformed the health of nations, by eliminating the spread on many diseases that thrive on poor sanitation and sewage. Given that our goal is to become a upper middle income country in 5-7 years, and a high income country in 25 years, we need to develop ***State level grids for collecting, processing and recycling sewage and solid waste*** in the next ten years.

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[30] Swachh Bharat Grameen phase2 is already emphasizing solid & liquid waste management in Open defecation free village.

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Appendix

Table A.1: Descriptive Statistics (2015-16)

Variable	n	Mean	S.D.	Median	Min	Max
Per Capita Net State Domestic Product	29	91877.69	52494.69	88609	24064	280000
Stunted children (%)	29	32.99	7.49	32.5	19.7	48.3
Wasted children (%)	29	18.55	5.57	18.1	6.1	29
Underweight children (%)	29	28.39	9.89	28.9	12	47.8
Sanitary sewer system-Private toilet (%)	29	50.37	19.63	49.8	23.4	88.6
Sanitary sewer system-shared toilet (%)	29	7.46	3.97	6.7	0.8	19.4
Unimproved sanitation (%)	29	32.63	20.46	32.1	1	70.5
Open Defecation (%)	29	26.12	22.56	20.8	0.2	69.9
Child mortality	29	40.42	15.21	37.6	7.1	59.8
Female schooling	29	38.21	12.5	34.3	22.8	78.1
Source: NFHS 4 (2015-16)						

Table A.2: Low (14) and High (14) Open defecation states with Nutrition

Independent variables	Stunted	Stunted	Underwt	Underwt
(S.E. in brackets)				
SS- private toilet	-0.11***	-0.1**	-0.16***	-0.14***
	(0.03)	(0.03)	(0.03)	(0.03)
Sanitation and sewage system-shared toilet	-0.86***	-1.02***	-1.11**	-1.08***
	(0.30)	(0.32)	(0.28)	(0.30)
Eod= Actual OD- Predicted OD	0.18***	0.15**	0.20***	0.18***
	(0.06)	(0.06)	(0.05)	(0.05)
Iron rich foods (low OD states)	-0.06		-0.09	
	(0.12)		(0.11)	
Iron rich foods (high OD states)	0.13		0.08	
	(0.11)		(0.10)	
Vit A-rich foods (low OD states)	0.13	0.10		-0.07
	(0.11)	(0.12)		(0.11)
Vit A-rich foods (high OD states)	0.13	-0.008		-0.01
		-0.09		(0.08)
R squared	0.52	0.50	0.68	0.67
Adjusted R squared	0.42	0.39	0.62	0.60
No. of observations	28	28	28	28
Note: * =p < 0.10; ** = p < 0.05; ***= p <0.01.				
Data Source: NFHS 4 and 5; Note: All regressions are in first difference				

Table A.3 presents the estimates of equation 8, when malnutrition is measured by the percentage of underweight children. As in table 7, female education remains significant at 1% level of significance when all other variables are tested for in the model. Underweight children are also found to be a significant determinant of child mortality. All the variables represented by K_i are found to be insignificant.

Table A.3 Effect of Nutrition and Vaccination on Child mortality

Independent variables	**Under 5 mortality**				
(S.E. in brackets)					
Female education (>10 years)	-1.17***	-1.23***	-1.23***	-1.13***	-1.09***
	(0.16)	(0.17)	(0.24)	(0.17)	(0.18)
Underweight children	0.56**	0.53**	0.47*	0.55**	0.53**
	(0.22)	(0.23)	(0.23)		(0.25)
Vitamin A rich foods	0.20***				
	(0.12)				
Iron rich foods		0.103			
		(0.14)			
Basic vaccination			0.008		
			(0.103)		
No. of Anganwadi workers				0.00018	
				(0.00014)	
Diarrhoea					-0.07
					(0.38)
R squared	0.75	0.73	0.72	0.690	0.67
Adjusted R squared	0.72	0.69	0.69	0.654	0.63
No. of observations	27	27	28	29	29
Note: * =p < 0.10; ** = p < 0.05; ***= p <0.01.					
Data Source: NFHS 4 and 5, Economic Survey 2023-24 Statistical Appendix					
Note: all regressions are in first difference					

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