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Authors: Charlotte Lee, Monica Lakhanpaul, Bernardo Maza Stern, Priti Parikh
Affiliations: university college london[1]
Orcid ids: 0000-0001-8252-9538[1]
Contact e-mail: charlotte.lee.12@ucl.ac.uk

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TITLE PAGE

Associations between the household environment and stunted child growth in rural India: a cross-sectional analysis

Charlotte Lee [a, b, 1], Monica Lakhanpaul [a, b], Bernardo Maza Stern [c], and Priti Parikh [c *]

a. *Whittington Health NHS Trust, Magdala Avenue, London N19 5NF, United Kingdom.*
b. *UCL Great Ormond Street Institute of Child Health, University College London, 30 Guildford Street, London WC1N 1EH, United Kingdom.*
c. *Department of Civil, Environment and Geomatic Engineering, University College London, 117 Chadwick Building, Gower Street, London WC1E 6BT, United Kingdom.*

***Corresponding Author and reprint requests to:** Dr. Priti Parikh, Department of Civil, Environment and Geomatic Engineering, University College London Civil, 117 Chadwick Building, Gower Street, London WC1E 6BT, United Kingdom; email: priti.parikh@ucl.ac.uk.

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[1]Present address: Nuffield Department of Primary Care Health Sciences, University of Oxford, Radcliffe Primary Care Building, Radcliffe Observatory Quarter, Woodstock Road, Oxford, OX2 6GG.

ABSTRACT

Stunting is a major unresolved and growing health issue for India. Yet there remains scant evidence for the development and application of integrated, multifactorial child health interventions across India's most rural communities. We examine the associations between household environmental characteristics and stunting in children under 5 years across rural Rajasthan, India. We used DHS-3 India data from 1194 children living across 109,041 interviewed households. Multiple logistic regression analyses independently examined the association between (1) main source of drinking water, (2) main type of sanitation facilities, (3) main cooking fuel type, and (4) agricultural land ownership and stunting adjusting for child age. After adjusting for child age, household access to (1) improved drinking water source was associated with a 23% reduced odds (OR=0·77, 95% CI 0·5 to 1·00), (2) improved sanitation facility was associated with 41% reduced odds (OR=0·51, 95% CI 0·3 to 0·82), and (3) agricultural land ownership was associated with a 30% reduced odds of childhood stunting (OR 0·70, 95% CI 0·51 to 0·94). Cooking fuel source was not associated with stunting. Although further research is needed, intervention programmes should consider shifting from nutrition-specific to nutrition-sensitive solutions to address India's childhood malnutrition crisis. Results and implications are discussed.

KEYWORDS: environment; water; sanitation; agriculture; cooking; malnutrition; stunting; growth, India, rural

STATEMENT OF ROBUSTNESS

The Millennium Development Goals (MDGs) and Sustainable Development Goals (SDG) have together galvanised efforts to meet the needs of the worlds most disadvantaged. India has seen unprecedented economic growth. Yet health improvements in rural communities remain unparalleled, with 42% of children under five years reported as being stunted. The first 1000 days is a period of growth exceptionally environmentally sensitive, and a child's home represents their earliest exposure to the extrauterine environment. A better understanding of the extent to which wider environmental factors impact on stunted growth is paramount to inform national strategies and intervention programmes including the recently launched (2017-18) National Nutrition Mission. Our study lends support to an onus that now optimises nutritional outcomes for young children using a wider multi-sectorial framework and concerted efforts by policy makers, researchers, and private sector change agents alike.

1. INTRODUCTION

Globally, 150·8 million children under 5 are stunted. In 2018 India held almost one third (46·6 million) of the world's stunting burden (International Institute of Population Sciences [IIPS], 2016). Stunting – or low height-for-age growth - is the most prevalent form of growth failure and yet the most unnoticed. The first 1000 days is a period of growth exceptionally environmentally sensitive. Malnutrition during this critical period of development has lasting effects that transcend generations. These include long-term effects on cognitive development (Walker *et al*., 2007), school achievement (Semba *et al*., 2008), adult economic productivity (Hoddinott *et al*., 2008), maternal reproductive outcomes (Dewy *et al*., 2011), and risk for obesity and non-communicable diseases (Guerrant *et al*., 2013). UNICEF recognises the first 1000 days as a critical window of opportunity during which timely interventions may have a measurable and lasting impact on health.

Stunting is the result of chronic malnutrition and reflects the complex interaction between intergenerational socio-economic, cultural-behavioural, and environmental risk and protective factors (Smith *et al*., 2005). A child's household represents one of their earliest exposures to the extrauterine environment. So far, evidence suggests household characteristics including improved water access (Torlesse *et al*., 2016), improved sanitation practices (Rah *et al*., 2015; Spears *et al*., 2013), access to clean fuels (Tielsch *et al*., 2009), and agricultural land ownership (Pandey *et al*., 2016) may positively impact on nutritional status for children under 5 years across urbanised Indian states. However, it is less clear how these household characteristics impact on stunting across India's most rural communities.

Studies that have focused on stunting across rural India have found rates to be significantly higher among children from low-income families and/or from households identified as belonging to Scheduled Castes or Tribes (59%), compared with middle- and high-income families (33%; HUNGaMA, 2011). One example of a rural part of India is Rajasthan, a landlocked state in north-west. It is characterised by large numbers of tribal groups (75%), compared with urban areas (25%), and low female (42%) relative to male (76%) literacy rates (Census of India, 2011). Illiteracy is a known influence of informed decision making, personal empowerment, and community participation in health initiatives (Coulombe *et al*., 2006). As such, current state-wide nutrition-specific initiatives alone may be insufficient in promoting optimal growth for India's most rural and vulnerable communities.

The emerging picture is that access to safe water, adequate sanitation and hygiene may reduce the risk of diarrheal morbidity, parasitic infection, and environmental enteropathy (Dearden *et al*., 2005); in turn, helping ameliorate risk of stunting (Fink *et al*., 2011). The evidence on the influence of cooking fuels and stunting is less clear. Whilst most studies have focused on outdoor air pollutant, a growing body of evidence suggests a link between indoor use of traditional biomass fuels (e.g. wood, agricultural, animal waste) and stunting, compared with energy efficient fuels such as liquefied petroleum gas (LPG)/natural gas or electricity (Rohner *et al*., 2013). Additionally, agricultural land ownership offers food security, adequate dietary intake and may protect against stunting. Of knowledge, few studies have examined the extent to which indoor cooking fuels and agricultural land ownership influences stunting for rural households.

Notwithstanding, stunting rates are well documented across India. However, the specific household determinants of stunting among India's most rural communities are not clearly understood (Biswas *et al*., 2010). There remain scant evidence-based, multi-sectorial strategies that consider and combine the wider determinants of stunting, or that sufficiently differentiate between population subgroups. This is an important omission and may partly explain why current nutrition-specific initiatives have failed to address the growing global health issue of stunting across rural India. Therefore, this study aims to identify which household environmental characteristics are associated with childhood stunting as a first-step towards better informing current national strategies and intervention programmes. Specifically, we examine the associations between (1) main drinking water source, (2) main type of sanitation facilities, (3) main cooking fuel, and (4) ownership of agricultural land and stunting in children under 5 years from Rajasthan as an exemplar rural community at-risk of stunting by virtue of their economic and educational position.

2. METHOD

2.1. Data Source

We examine the Demographic Health Survey (DHS-3) carried out by the International Institute for Population Services (IIPS) in 2005-2006. Details are fully described by the IIPS (2006). Briefly, a stratified multistate cluster sampling method identified a nationally representative sample of India's population living in both urban and rural areas in 29 states. The fieldwork for gathering the data was carried out between November 2005 and August 2006 and included data on 515,597 individuals from 109,041 interviewed households across India. The three core questionnaires of the DHS-3 are the Household Questionnaire, the Women's Questionnaire, and the Men's Questionnaire and pertain to indicators in the areas of population, health, and nutrition. In the current study we examine data from the Household Questionnaire, which includes the following information:

a) Household Schedule: age, sex, relationship to the head of the household, education, parental survivorship and residence, and birth registration.
b) Household characteristics: drinking water, toilet facilities, cooking fuel, and household assets.

2.2. NFHS-3 Data Collected and Study Indicators

All interviews and anthropometric measurements were collected as part of the DHS-3. The IIPS (2006) fully describes data collection procedures. In short, each household respondent was invited to provide informed consent. Parents or guardians provided consent for infants and children. The field interviewers and anthropometrists were from local non-government organisation (NGO) partners and were trained before data collection. The performance of field staff during data collection is reported as continuously monitored by supervisors and quality control teams who rechecked some of the data the following day to ensure reliability. Non-response and refusal to participate in the surveys is reported as minimal (IIPS, 2006).

2.2.1. Household Environmental Characteristics

DHS-3 interviews were carried out using structured questionnaires. During the Household Questionnaire, respondents could select only *one* of the following sub-categories pertaining to each household category:

1) Main drinking water source: piped into dwelling, piped into yard, public tap, borehole, protected well, unprotected well, unprotected spring, groundwater, rainwater, and tanker truck or cart.
2) Main sanitation facility: flush to piped sewer system, flush to septic tank, flush to pit latrine, flush elsewhere, and ventilated pit latrine, pit latrine with slab, pit latrine without slab, no facility/field/bush, and dry toilet or other.
3) Main cooking fuel source: LPG/natural gas, kerosene, charcoal, wood, straw/shrubs/grass, agricultural waste, and animal waste.
4) Agricultural land ownership: yes or no.

2.2.2. Anthropometry

The length of each child per household (at 0-23 months) was measured in a recumbent position to the nearest 0.1cm using a measuring board. The height of each child (>24 months) was measured in a standing, upright position to the nearest 0.1cm using a vertical board with a detachable sliding headpiece.

2.2.3. Other (confounding) Variables

The age of the child is a known influence of stunting and hence controlled for in the current study. Infants and children have predominantly different feeding practices. A breastfed infant receives the majority of their nutrient requirements from breast milk and consume little else. Conversely, children who start to grow, crawl, walk, explore and put objects in their mouths risk themselves ingesting bacteria from human and animal sources. The household respondent gave the child's age at the time of administering the DHS-3 questionnaire. Since it can be difficult for rural households to accurately estimate a child's age without a birth certificate or vaccination card, DHS-3 field staff used a local events calendar to determine the month and year of birth of the case. The child's age in months was calculated using the country's month code for the date of the interview, minus the country's month code for the date of birth of the child. This study follows the World Health Organisation (WHO, 2015) standard by analysing the following age categories: <6 months, 6-24 months, and 24-60 months. No other child (sex) or caregiver (Scheduled caste or tribe) characteristics were associated with stunting and hence not included as confounding variables.

2.3. Statistical Analyses

We statistically analyse DHS-3 secondary data in SPSS 25 (IBM Corp, 2017). In order to analyse the data, first missing or incorrectly recorded data was removed from the database. Only children under 5 years (herein cases U5) with available information on age, sex and height were retained in the dataset. All cases U5 per household were included in the analyses. The final number of cases with available data (N=1194) formed the basis of the analyses. Second, stunting indices were calculated as per the WHO child growth standards using the age and height data collected and defined as height-for-age (HAZ) z-scores less than 2 from the median HAZ of a reference population (WHO, 2015). Third, improved drinking water source was dichotomised into *improved* (piped into dwelling, piped into yard, public tap, borehole, and protected well) versus *unimproved* as per WHO (2015) guidelines. As reported elsewhere (Rah *et al.*, 2015) sources of sanitation facilities were also dichotomised into *improved* (including flush to piped sewer system, flush to septic tank, flush to pit latrine, flush elsewhere, ventilated pit latrine, and pit latrine with slab) versus *unimproved*. Improved cooking fuel was dichotomised as *improved* (LPG/natural gas and kerosene) vs *unimproved* (Masera *et al.*, 2000). Fourth, descriptive statistics were used to examine the distribution of the full range of variables i.e. household characteristics and stunting. Lastly, a cross-tabulation with chi-square analyses were run as the main analyses. Where a significant association was found, a multiple logistic regression model was used to independently examine the association between household characteristics and stunted cases (0=not stunted; 1=stunted) adjusting for infant age category as a potential confounder. Household characteristics were included as the independent variables and stunting was included as the dependent variable. The odds ratio (OR) and corresponding 95% confidence intervals (CI) were estimated with statistical significance defined as $p \leq 0.05$.

3. RESULT

3.1. Descriptive Statistics

3.1.1. *Demographic Characteristics*

The mean age (±SE) of cases U5 in the analyses was 29.9±0.51 months, 53% were male and 81% belonged to Scheduled castes. Approximately 44.5% of the sample were stunted. Stunting cases significantly differed by age category $F(1)=51.35$, $p \leq 0{\cdot}001$, all levels significant. Hence, only case age was adjusted for in the following regression analyses (Table 1).

Of the 1194 cases, 72·3% of cases belonged to families reported as using an improved main source of drinking water source, with a borehole as main source of drinking water (44·1%). Only 7·6% belonged to families that used improved sanitation facilities, and 91% used no sanitation facility. Only 3·1% of cases belonged to families reported as using an improved source of cooking fuel, with biomass fuel wood as the commonest source (85%). Lastly, 224 cases (18·8%) belonged to families reported as owning agricultural land, whilst 970 cases (81·2%) belonged to families that did not own agricultural land (Table 1).

Table 1. Characteristics of cases under 5 years included in the sample

Demographic Characteristics	**Total Sample (*N*=1194)**	**Stunted (*n*=532)**	**Not Stunted (*n*=662)**
Child Age (months), *M* (±SE)	29.98±0.51	33.32±0.67	27.31±0.73
Child Sex, *n* (%)			
Male	636 (53.3%)	285(53.6%)	351 (53%)
Female	558 (46.7%)	247 (46.4%)	311 (47%)
Caregiver Schedule	-	-	-
Caste	976 (81.7%)	425 (79.9%)	551 (83.2%)
Tribe	218 (18.3%)	107 (20.1%)	111 (16.8%)
Stunted (HAZ <-2), n (%)			
No	662 (55.5%)	-	-
Yes	532 (44.5%)	-	-
Stunting (HAZ <-2), M (±SE)	-1.80 (1.76)	-3.34 (0.04)	0.56 (1.18)
Drinking Water Source, n (%)			
piped into dwelling	17 (1.4%)	5 (0.9%)	12 (1.8%)
piped into yard	107 (9%)	50 (9.4%)	57 (8.6%)
public tap	195 (16.3%)	91 (17.1%)	104 (15.7%)
borehole	527 (44.1%)	223 (41.9%)	304 (45.9%)
protected well	18 (1.5%)	8 (1.5%)	10 (1.5%)
unprotected well	221 (18%)	110 (20.7%)	111 (16.8%)
unprotected spring	2 (0.2%)	-	2 (0.3%)
groundwater	35 (2.9%)	16 (3.0%)	19 (2.9%)
rainwater	28 (2.3%)	7 (1.3%)	21 (3.2%)
tanker truck	14 (1.2%)	7 (1.3%)	7 (1.1%)
cart	30 (2.5%)	15 (2.8%)	15 (2.3%)
Sanitation Facility, n (%)			
flush to pipe sewer system	1 (0.1%)	-	1 (0.2%)
flush to septic tank	43 (3.6%)	16 (3.0%)	27 (4.1%)
flush to pit latrine	27 (2.3%)	4 (0.8%)	23 (3.5%)
flush elsewhere	1 (0.1%)	1 (0.2%)	-
ventilated pit latrine	1 (1.1%)	1 (0.2%)	-
pit latrine with slab	17 (0.4%)	6 (1.1%)	11 (1.7%)
pit latrine without slab	11 (0.9%)	4 (0.8%)	7 (1.1%)
no facility/field/bush	1088 (9.1%)	498 (93.6%)	590 (89.1%)
dry toilet	2 (0.2%)	1 (0.2%)	1 (0.2%)
other	3 (0.3%)	1 (0.2%)	2 (0.3%)

Cooking Fuel Source			
LPG/natural gas	33 (2.8%)	9 (1.7%)	24 (3.6%)
kerosene	4 (0.3%)	1 (0.2%)	3 (0.5%)
charcoal	4 (0.3%)	2 (0.4%)	2 (0.3%)
wood	1021 (85%)	455 (85.5%)	566 (85.5%)
straw/shrubs/grass	71 (5.9%)	33 (6.2%)	38 (5.7%)
agricultural waste	32 (2.7%)	13 (2.4%)	19 (2.9%)
animal waste	29 (2.4%)	19 (3.6%)	10 (1.5%)
Agricultural Land Ownership			
no	224 (18.8%)	116 (21.8%)	108 (16.3%)
yes	970 (81.2%)	416 8.2%)	554 (83.7%)

Table 2. Odds ratio and chi-squares for household characteristics on stunting (HAZ <2) standardized coefficients and confidence intervals.

Household Characteristics (*N* = 1194)		**OR**	**X^2**
Drinking Water Source			
	Unimproved	1[Reference]	3.24 (1)
	Improved	0.78 (0.60-1.02)	
Age Category			
0-5	Unimproved	1[Reference]	0.24 (1)
	Improved	0.76 (0.26-2.21)	
6-23	Unimproved	1[Reference]	6.27 (1)*
	Improved	0.53 (0.32-0.87)	
24-59	Unimproved	1[Reference]	0.27 (1)
	Improved	0.91 (0.65-1.27)	
Sanitation Facilities			
	Unimproved	1[Reference]	7.87 (1)**
	Improved	0.51 (0.32-0.82)	
Age Category			
0-5	Unimproved	1[Reference]	1.39 (1)
	Improved	2.32 (0.55-9.67)	
6-23	Unimproved	1[Reference]	1.54 (1)
	Improved	0.58 (0.24-1.37)	
24-59	Unimproved	1[Reference]	8.96 (1)**
	Improved	0.40 (0.22-0.74)	
Cooking Fuel			
	Biomass	1[Reference]	4.01 (1)*
	Improved	0.50 (0.25-0.99)	
Age Category			
0-5 Months	Biomass	1[Reference]	1.11 (1)
	Improved	0.84 (0.77-0.91)	
6-23 Months	Biomass	1[Reference]	0.44 (1)
	Improved	1.13 (0.34-3.80)	
24-59 Months	Biomass	1[Reference]	4.63 (1)*
	Improved	0.38 (0.15-0.94)	
Agricultural Land Ownership			
	No	1[Reference]	5.83 (1)*
	Yes	0.69 (0.52-0.93)	
Age Category			
0-5 Months	No	1[Reference]	0.20 (1)
	Yes	0.75 (0.22-2.55)	
6-23 Months	No	1[Reference]	0.24 (1)
	Yes	0.87 (0.50-1.51)	
24-59 Months	No	1[Reference]	5.93 (1)*
	Yes	0.62 (0.43-0.91)	

[a]Chi-square statistic with degrees of freedom and odds ratios with 95% confidence intervals
[b]* $p < 0.05$, ** $p < 0.01$. Models include child age in months.
[c]Improved sources of sanitation facilities: to piped sewer system, flush to septic tank, flush to pit latrine, flush elsewhere, ventilated pit latrine and pit latrine with slab.
[d]Improved drinking water source: piped into dwelling, piped into yard, public tap, borehole, and protected well (WHO, 2018) versus unimproved.
[e]Improved cooking fuel: LPG/natural gas and kerosene.

3.2. Results from Main Analyses

3.2.1. *Drinking water source and stunting outcome*

Results from the chi square analyses are reported in Table 2. An unadjusted logistic regression model reported drinking water did not predict stunting outcome (unadjusted OR=0·78, 95% CI 0·60 to 1·02, *p*=0·72). There was a significant relationship between drinking water source and stunting when controlling for age category (adjusted OR=0·77, 95% CI 0·58 to 1·00, *p*=0·05), with a 23% decreased odds of stunting for children consuming water from improved sources in comparison to those who use unimproved sources (Table 3).

2.1.1. *Sanitation facility and stunting outcome*

Unadjusted models reported a significant association between sanitation facility and stunting (unadjusted OR=0·51, 95% CI 0·32 to 0·82, *p*=0·006). This effect remained after adjusting for age (adjusted OR=0·51, 95% CI 0·32-0·83, *p*=0·007), with a 41% decreased odds of stunting for children with access to improved sanitation facilities in comparison to those without access (Table 3).

2.1.2. *Cooking fuel source and stunting outcome*

There was a significant unadjusted association between cooking fuel and stunting outcome (unadjusted OR=0·50, 95% CI 0·25 to 0·99, *p*=0·49). This association was not significant after adjusting for age (adjusted OR=0·51, 95% CI 0·25 to 1·03, *p*=0·061; Table 3).

2.1.3. *Agricultural land ownership and stunting outcome*

There was a significant association between agricultural land ownership and stunting (unadjusted OR=0·69, 95% CI 0·52 to 0·93, *p*=0·016). This association remained significant after adjusting for age (adjusted OR=0·70, 95% CI 0·51 to 0·94, *p*=0·20), with a 30% decreased odds of stunting in children whose family owned agricultural land, compared with children without agricultural land ownership (Table 3).

Table 3. Logistic regression models for household characteristics on stunting (HAZ <-2) standardized coefficients and confidence intervals.

Household Characteristics (*N*=1194)	***n***	**Crude OR (95% CI)**	**Adjusted OR (95% CI)**
Drinking Water Source			
Unimproved	1105	1[Reference]	1[Reference]
Improved	89	0.78 (0.60-1.02)	0.77 (0.58-1.00)
Sanitation Facility			
Unimproved	302	1[Reference]	1[Reference]
Improved	892	0.51 (0.32-0.82)*	0.51 (0.32-0.83)*
Cooking Fuel Source			
Unimproved	1153	1[Reference]	1[Reference]
Improved	41	0.50 (0.25-0.99)*	0.51 (0.25-1.03)
Agricultural Land Ownership			
No	224	1[Reference]	1[Reference]
Yes	970	0.69 (0.52-0.93)*	0.70 (0.51-0.94)*

[a] *$*p < 0.05$, $**p < 0.01$. All adjusted models include child age in months.*
[b] *Improved sources of sanitation facilities: to piped sewer system, flush to septic tank, flush to*
[c] *pit latrine, flush elsewhere, ventilated pit latrine and pit latrine with slab.*
[d] *Improved drinking water source: piped into dwelling, piped into yard, public tap, borehole, and protected well (WHO, 2018) versus unimproved.*
[e] *Improved cooking fuel: LPG/natural gas and kerosene.*

3. DISCUSSION

In this study we found that reported household use of (1) improved drinking water source was associated with a 23% reduced odds, (2) improved sanitation facility was associated with 41% reduced odds, and (3) agricultural land ownership was associated with a 30% reduced odds of child stunted growth. Indoor cooking fuel source was not associated with risk of stunting although did approach trend level.

Overall, our results on the association between sanitation facilities and stunting support findings of other cross-sectional studies across rural India. These studies report that improved sanitation is associated with lower risk of stunting (Dearden *et al*. 2017; Smith *et al*., 2015).

Studies have also shown that caregiver self-reported hand washing with soap either after open defecation or before infant feeding offers protective effects for child malnutrition (Meshram *et al*., 2013; Mbuya *et al*., 2016) and that personal hygiene offers stronger improvements on stunting than improved household access to water and sanitation alone (Rah *et al*., 2015).

Open defecation is widely considered a marker of sanitation. It increases risk of spreading bacterial, viral, and parasitic infections including diarrhoea, polio, cholera and hookworm. Frequent diarrhoeal episodes reduce resistance to infections (Chambers *et al*., 2013), and further affect stunting (Spears *et al*., 2013) and infant mortality (Hathi *et al*. 2017). The DHS-3 dataset highlights that 91% of households openly defecate. The Indian Census (2011) found that 70% of rural households do not have access to a toilet or latrine. This differs from figures published by the Government of India's Swachh Bharat Abhiyan mission where the state of Rajasthan is listed as Open Defecation Free (Government of India, 2014).

Nonetheless, India's widespread open defecation and high population density constitutes a double threat. The economic impact of inadequate sanitation is estimated at 6·4% of gross domestic product (Chambers *et al*., 2013). Despite rapid economic growth, widespread access to improved water sources and improving literacy rates, affordability coupled with lack of access to water for maintenance of toilets is often seen as a barrier for latrine construction. Additionally, there is need for further work on sanitation service use and personal hygiene practices with local values and beliefs. Open defecation represents an interplay between material or educational deprivation and beliefs, values, and norms about purity, pollution, caste, and untouchability (Coffey *et al*., 2015). Parental formal education is reported as being associated with improved health outcomes in children under 5 years across Indonesia and Bangladesh (Semba *et al*., 2008). These outcomes include protective caregiving behaviours (such as handwashing with soap), complete childhood immunisations, improved sanitation (using lined pit latrines) and decreased odds of stunting. Although mothers are generally the primary caregiver, paternal education is also associated with decreased stunting odds. Education is promoted for both men and women in the MDGs which - through improved caregiving practice, job security, and income - may shift risk of stunting for India's most rural and vulnerable communities.

Currently, Indian sanitation policies construct pit latrines by focusing on the 'demand-side' approach. In practice, government programmes have neglected to understand why rural Indian communities openly defecate despite available lined pit latrines. Lined pit latrines require the construction of a concrete lined septic tank for safe storage of faecal matter, which then has to be safely disposed. This has led to construction of more affordable non-lined pit latrines, which potentially contaminates ground water. Hence the costs of construction of safe latrines coupled with requirements of safe disposal of faecal matter becomes a barrier for scale-up of sanitation in rural communities where centralised drainage systems for collection of sewage do not exist. Future rural sanitation programmes must ultimately address affordability and cultural beliefs, values, and norms around sanitation and should do so in ways that accelerate progress towards social equality for optimal child growth.

Household access to improved drinking water source was also associated with stunting, albeit to a lesser extent than improved sanitation access. This corroborates early findings that suggest the potential effects of improved water supply on child growth may be smaller than those of improved sanitation (Esrey *et al*., 1991). Overall, there is mixed evidence on the interaction between drinking water source and sanitation on child growth. Longitudinal studies have found positive associations between improved water sources and child linear growth existed only when coupled with improved sanitation and water storage practices (Checkley *et al*., 2004). In addition, improved sanitation, rather than improved water source, have been associated with lower risk of stunting in India (Dearden *et al*., 2017) and Sudan (Merchant *et al*., 2003). More recently, randomised controlled trials in Bangladesh report no long-term benefits of integrated water, sanitation and handwashing, compared with sanitation interventions alone (Luby *et al*., 2018). Further research is required to determine if improved household water supply, its treatment, handling and storage, combined with sanitation practices have synergistic or additive effects on child growth. As noted above, the major pathways of faecal-oral transmission of bacteria may be different for infants compared with adults. Infants who are breastfed receive the majority of their nutrients from breast milk and consume little amounts of drinking water. As children start to grow, crawl, walk, explore and put objects in their mouths, the risk of ingesting bacteria from human and animal faeces increases. Thus, the number of bacteria they ingest from contaminated water may be comparatively smaller.

Previous studies have reported associations between agricultural land ownership and nutritional status in children and adolescents across rural India (Bentley *et al*., 2015; Rao *et al*., 2000). Land holding is central to income generation and the provision of affordable, diverse, nutrient-rich foods for rural communities. Children of rural communities often live in close proximity to livestock, directly influencing nutrient intake. Hence promoting agricultural and livestock production is a common development strategy. However, few studies have examined the direct effect on child nutrition (Jin & Iannotti, 2014). These studies suggest livestock may serve as direct source of protein through meat, milk, and eggs or indirectly by increasing household income for food expenditure. However, rural communities may be differentially vulnerable to food insecurity due to seasonal isolation (i.e. lack of grazing land) and economic deprivation (i.e. high treatment costs for diseased animals; Yadav *et al*., 2016). Furthermore, as abovementioned, livestock ownership may increase exposure to environmental feacal material. Further research is necessary to understand the effect of agricultural land ownership on stunting.

We found no association between cooking fuel and stunting. Biomass fuels release particulate matter, carbon monoxide, and other toxins at a much higher rate than kerosene and LPG. Rural households often rely on traditional biomass fuels for their household cooking and heating; burned in simple, inefficient, and mostly unvented cook stoves that generate large volumes of indoor smoke. Biomass fuel exposure is usually much greater among women, who tend to do most of the cooking (Behera *et al*., 1988), and among young children who often stay indoors and are carried on their mother's back or lap while she cooks (Albalak *et al*., 1999). A child's developing lungs are susceptible to irritation and contamination when exposed to biomass fuels and hence may experience excessive respiratory infections (Tielsch *et al*., 2009). However, the possible systemic effects on child growth have yet to be explored (Fullerton *et al*., 2008; Mishra *et al*., 2017). It is also possible that households in our DHS-3 sample used a combination of both biomass and improved fuels Nonetheless, in May 2016 the Indian government began providing below-poverty-line households with LPG connections through the Government of India Ujjawala Scheme and NGOs are currently working to replace traditional cooking stoves with more efficient ones. A permanent transition to clean fuels is perhaps needed and low-cost ventilation solutions offer potential to impact on adverse child health outcomes. It is also worth noting that barriers to uptake of clean energy range from affordability to perception of food tasting different if a different fuel source is used.

Our study has limitations. First, our study is correlational and we cannot infer causation. Also, the survey did not assess baseline anthropometry in the mother or child e.g. birth weight and height. Longitudinal data will help avoid confounding due unobserved child- or time-varying contextual factors. Second, the effects of household characteristics are likely to be underestimated such that measurement constraints did not permit acknowledgment of any previous or ongoing interventions designed to improve child malnutrition. Third, the DHS-3 allows one selected answer in each category. Yet, households often have multiple sources of drinking water, sanitation and cooking fuels and the DHS-3 did not collect information related to consumption frequency and quality of drinking water. Additionally, children who are schooled, work and/or use public toilets may be exposed to other environmental pathogenic risks of stunting outside of the home. If so, there is greater cause for concern since our results may underestimate the true associations of environmental determinants and anthropometry. Of knowledge, the DHS-4 will include more open-ended questions (e.g. '*how do you clean water*'), which will allow for a comprehensive analyses of household environmental practices on childhood stunting. Fourth, although improved water source is used an indicator of higher probability of safe water the DHS-3 data did not include biological indicators of pathogenic contamination that might influence infection risk.

4. CONCLUSIONS

Understanding the environmental determinants of stunting is a critical step in strengthening the relevant evidence base towards developing multi-sectoral interventions for optimal child growth. Our results lend support to the MDG, SDG, 2016-30 Global Health Strategy, and Nutrition Mission, which all emphasise the provision of multisector enablers for optimal nutrition. The onus now is to optimise nutrition-related outcomes for young children using a framework that is broader than nutrition-specific interventions alone. India's most vulnerable children need to benefit from interdisciplinary research and integrated, cross-sector interventions that can support environmental improvements in tandem with nutrition-sensitive programmes and awareness campaigns. Stunting and child health is dependent on a multitude of factors at household and community level, which requires concerted efforts by policy makers, researchers, and private sector partners.

LIST OF ABBREVIATIONS

DHS: Demographic Health Survey; HAZ: height-for-age; IIPS: International Institute for Population Services; LPG: liquefied petroleum gas; MDG: Millennium Development Goals;

NGO: Non Government Organisation; SDG: Sustainable Development Goals; WASH: water and sanitation for health; WAZ: weight-for-age; WHO: World Health Organisation; WHZ: weight-for-height; U5: under 5 years.

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Consent for Publication: Not applicable.

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